PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 11, NO. 3 ▽ MAY, 1930

A FEDERAL-AID ROAD IN PENNSYLVANIA

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A TECHNICAL BASIS FOR APPORTIONING MOTOR VEHICLE TAXES[1]

By CHARLES F. MARVIN, Jr., Mechanical Engineer, Heat and Power Division, U. S. Bureau of Standards

THE rapid increase in motor transportation which has occurred in the past 30 years would not have been possible without the highway improvements and extensions which have accompanied the development of the motor car.

These highway improvements and extensions threw upon the State and local governments a great additional financial burden which, with their existing revenue systems, they were ill-prepared to assume. Since no part of this increase in highway expenditures could be attributed to any factor other than the new demands of automobile traffic, it seemed equitable and expedient to impose special taxes on motor vehicle owners to meet the cost, in part at least, of the special service provided. After years of application, State registration or license fees and fuel taxes have come to be accepted as just and logical forms of taxation.

However, at the present time there is no generally accepted basis for determining the amounts of fees for the various classes of vehicles or the units within a class. Neither is there any agreement as to how the total tax levied by a State should be apportioned between the fuel tax and registration fees. Each State has selected its own method of levying fees with the result that at the present time vehicles are rated according to chassis weight, unladen weight, capacity, gross weight, horsepower, piston displacement, value, tire width, or tire type as well as on several different combinations of two or more of these characteristics. In many cases there is no definite relation between the characteristic used as a base and the justification for taxing or the amount of fee charged. Some States rate passenger cars and trucks on the same basis while others do not. Several States have sacrificed simplicity of administration in an effort to obtain more equitable fees, while other States, apparently aiming at simplicity, have prescribed fees which seem inconsistent in their distribution of the tax burden among vehicles of different characteristics. All of the States and the District of Columbia impose fuel taxes of from 2 to 6 cents a gallon, but there is no consistent relation between the amounts of the fuel taxes and the amounts of registration fees.

Several years ago the motor vehicle and highway departments of the State of Connecticut requested the Bureau of Standards to undertake a study of current systems for taxing motor vehicles with a view to eliminating some discrepancies in the Connecticut system and, if possible, to find a more logical and equitable basis for such taxation.

The present paper is a revision of the report which was submitted to the State of Connecticut, with the material of general interest rearranged to emphasize the principles involved and with those portions applying only to Connecticut omitted.

It was not within the scope of the investigation to recommend a total revenue to be collected from motor vehicle owners, or to fix the relation between such a total and the total highway expenditures. Each State must determine for itself how much it wishes to spend on highways and what percentage of this amount should be financed by motor vehicle taxes, taking into account general social benefits and benefits to property which may be expressed by general appropriations and property taxes. The purpose of the bureau's investigation was to recommend a simple and equitable method of distributing a total tax levy, determined by the State, among the various classes of vehicles and the units within a class as nearly as possible according to the amount and character of each vehicle's use of the public streets and roads. In this distribution no attempt was made to devise methods of collecting taxes on a basis of earning capacity or ability to pay. No discrimination was made as between privately operated vehicles and those operated for hire or by dealers. If such discriminations are thought advisable, they may be made in the form of a separate or an additional tax.

NECESSARY ELEMENTS OF A SATISFACTORY TAX SYSTEM

Equity.—A satisfactory tax system must first of all be equitable, that is, it must distribute the cost among the different vehicles in such a manner that each vehicle is assessed according to the justification for taxing such vehicle. The greatest and most evident justification for taxing is to defray the expenses incurred by the State due to the operation of the motor vehicles, and the first approximation to an equitable system would be one which would tax each vehicle in proportion as that vehicle is responsible for these expenses. It is also desirable in the interests of public utility, and convenience, that taxes should be so imposed that they penalize wherever possible those vehicles which are inefficient in their use of the highways or the nation's fuel resources, and thus encourage a relative increase in vehicles which bring about improvement and progress in highway transportation.

The expenses incurred by the State due to the operation of a given vehicle and the desirability of the vehicle as a unit of transportation will depend, in varying degree, on such things as the weight, size, speed, capacity and tire equipment of the vehicle; the number of miles it travels during the taxable period; the type of road over which it operates; the manner in which it is cared for and operated; the amount of regulation it requires; and the character of the service which it renders.

Simplicity.—It is highly desirable that the process of administering taxes be as simple as possible. Unfortunately, the exactly equitable rating, depending as it does on so many inter-dependent factors of varying importance, would be extremely complex. Even if it could be exactly determined, it would be impractical to administer. All that can be hoped for is a compromise rating which will be equitable in the most important respects and sufficiently simple to be cheaply and efficiently administered.

[1] Publication approved by the Director of the Bureau of Standards of the United States Department of Commerce.

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Undoubtedly the major factors to be considered in taxing a vehicle are (1) the weight imposed upon the road surface by the vehicle and its load, (2) the number of miles it travels during the taxable period, and (3) the type of tire with which the vehicle is equipped. A system which attempts to include more factors than these becomes very unwieldy while one which neglects any one of the three does so at a serious loss of equity.

Adaptability.—The ideal tax system would be equally applicable to the taxing of all of the various classes of vehicles, readily adaptable to the requirements of any State, and capable of being easily modified to suit changing conditions in the same State, without alteration of the basic method of rating vehicles or the system of collecting fees.

The three factors, weight, miles traveled, and tire type, may well be used as bases for rating all vehicles and for determining fees in all States for some years to come. However, it will not be possible to use the same amounts or ranges of fees everywhere and for all time. Costs of highway construction as well as the types of road and the total mileages vary from State to State and from time to time. Vehicles in the different weight groups are distributed differently throughout the various sections of the country and the damage caused by vehicles of a certain class is not necessarily the same in one State as in another. For these reasons any general method for determining taxes must permit a wide range of tax schedules.

THE RECOMMENDED SYSTEM

The vehicle characteristic of most importance so far as the road is concerned is not the rated horsepower or the rated carrying capacity so often used in determining fees, but the gross weight of the loaded vehicle. It is gross weight which is actually carried by the roadway, gross weight which largely determines the amount of highway damage, and gross weight for which new bridges and highways must be designed. In addition, gross weight is the only characteristic common to all of the various types of vehicles which is, for each type, closely related to the use and consequent deterioration of the road. These facts combine to make gross weight the best single measure of the justification for taxing.

Since gross weight bears a definite relation to the justification for taxing, it should also be definitely related to the amount of tax by some formula which would insure a gradual and consistent variation in tax throughout the whole range of gross weights.

The general formula.—Almost any relation between tax and gross weight which is likely to be desired in practice can be represented algebraically with a fair degree of approximation by the following formula: $\text{Tax} = A + B \times (\text{gross weight}) + C \times (\text{gross weight})^2$ in which the tax is in dollars and gross weight is in tons.

Certain familiar types of tax schedule are represented by the three terms of the formula. Thus, the first term imposes a flat rate of A dollars. The second term, $B \times$ (gross weight), levies a constant rate of B dollars a ton, while the last term, $C \times (\text{gross weight})^2$, is in effect a surtax which imposes an increasing rate per ton, and therefore affects most noticeably the heavier vehicles. By the proper evaluation of A, B, and C, the characteristics of these three distinct types of schedules may be blended into a single schedule in any proportion desired. The wide diversity of schedules which can be obtained is indicated by the examples given in Figure 1. Still other types can be obtained by using negative signs.

Three sets of corresponding values of tax and gross weight which will indicate the general trend desired in the tax-gross weight relation will serve to fix the constants A, B, and C. Thus, if it is decided, for example, that the total annual tax (registration fee plus annual fuel tax) for the average vehicle of 10 tons gross weight should be \$200, as compared with \$75 for a 5-ton vehicle and \$15 for a 1-ton vehicle, then the formula becomes:

Total annual $\text{tax} = 5.55 + 8.34 \times (\text{gross weight}) + 1.11 \times (\text{gross weight})^2$* and the total annual taxes for average vehicles of other weights will be as shown by the heavy line in Figure 2. The numerical values given above and appearing in Figure 2 and Table 1 were chosen arbitrarily merely for illustration. For actual use they should be determined independently by the different States and changed from time to time to meet existing conditions.

The fuel tax.—The dotted lines in Figure 2 show how fuel taxes of different amounts affect vehicles of different weights traveling the same number of miles per year, in this case 6,000. It is obvious that a fuel tax alone can not impose the rapidly rising schedule of taxes generally required. The fuel tax, however, possesses several advantages over registration fees, chief of which is that it automatically taxes a vehicle directly according to the number of miles traveled. In addition, it is effective in distributing taxes in the proper directions, although not always in the desired amounts, according to other justifications for taxing.

Thus it brings in more revenue per mile from the heavy truck than it does from the light passenger car, and taxes the fully loaded vehicle more than the empty one.

The increase in the price of fuel, due to the tax, encourages greater economy in the design and operation of vehicles and penalizes the owner who operates a car which is wasteful of the Nation's fuel resources. Thus, the vehicle which is overweight, overpowered, which has an inefficient engine, an improperly adjusted carburetor, or excessive friction in any of its parts pays a higher tax per mile than the well-designed and well-cared-for vehicle of the same capacity.

A fuel tax brings in revenue from visiting cars from other States which would otherwise use the highways tax free.

A car which continuously maintains a high speed through the open country will burn more gasoline and therefore pay a somewhat higher tax than a similar car which is driven over the same roads at a moderate speed.

Vehicles which habitually operate in crowded districts where highway "rent" should be high and where expenses of regulating traffic are greatest will, on account of their frequent stops and starts, burn more fuel and therefore pay a higher tax per mile than similar vehicles operating in the open country.

These advantages, together with the fact that it is conveniently paid and simple to collect, have made the fuel tax an increasingly acceptable form of taxation.

To fully utilize the many advantages of the fuel tax, it should constitute the greatest proportion of the total tax which can be charged without overtaxing any class of vehicles. Usually, the most equitable fuel tax will be determined solely by the total annual

* See Appendix A.

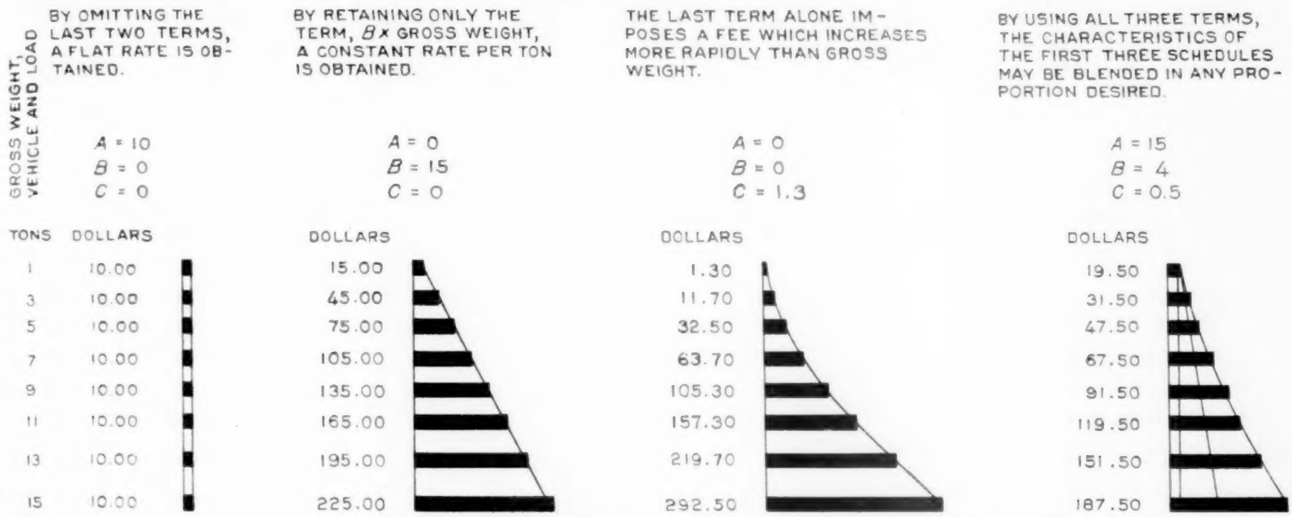

Figure 1.—Examples of the Various Types of Tax Schedules Obtainable by Varying the Constants in the General Formula: Tax $= A + B \times$ Gross Weight $+ C \times$ Gross Weight [2]

Table 1.—*Registration fees for pneumatic-tired vehicles according to formulas plotted in Figure 2, assuming a gasoline tax of 6 cents*

Gross weight of vehicle in tons	Fee in dollars	Gross weight of vehicle in tons	Fee in dollars
Up to 2	$1.00	6 to 7	$36.00
2 to 3	3.50	7 to 8	50.00
3 to 4	8.50	8 to 9	66.00
4 to 5	15.50	9 to 10	84.00
5 to 6	25.00	10 to 11	104.00

tax desired on the lightest class of cars. This is illustrated by the 6-cent fuel tax in Figure 2. If the total tax for the one-ton cars had been assumed as $10.00 instead of $15.00, the most equitable fuel tax would have been 4 cents instead of 6 cents per gallon.

In terms of the formula, the 6-cent tax becomes: Annual fuel tax $= 3.00 + 11.30 \times$ (gross weight).*

Registration fees.—There are some very important cases in which the justification for taxing is not measured exactly by the fuel consumption, and a fuel tax is therefore inadequate or ineffective.

A fuel tax does not provide a means of collecting from the heavier vehicles their share of highway costs. It can not penalize for the extreme width usually found in heavy trucks and busses. Also the type of tire used has only a small effect on fuel consumption but a very decided effect on road cost. Electrically driven vehicles pay no fuel tax at all, and this type must be taxed entirely by some other method.

Vehicles must be registered for purposes of record and identification and it is convenient at the same time to collect registration fees of sufficient amount to compensate for the inadequacies of the fuel tax.

Subtracting the above formula for fuel tax from the one previously given for total tax gives a formula for registration fees, thus:

$$\text{Total annual tax} = 5.55 + 8.34 \times (\text{gross weight}) + 1.11 \times (\text{gross weight})^2$$
$$\text{Annual fuel tax} = 3.00 + 11.30 \times (\text{gross weight})$$
$$\text{Registration fee} = 2.55 - 2.96 \times (\text{gross weight}) + 1.11 \times (\text{gross weight})^2$$

As shown in Figure 2 and Table 1, this equation gives very small registration fees for the light cars which are

* See Appendix A.

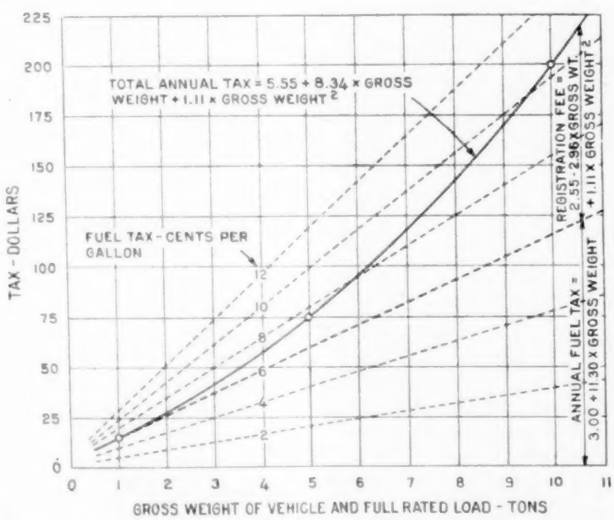

Figure 2.—Typical Tax Schedule Based on the Formula Tax $= A + B \times$ Gross Weight $+ C \times$ Gross Weight [2]

equitably taxed by the fuel tax alone, and is chiefly effective for the heavier trucks and busses for which the fuel tax is inadequate.

A still more rapidly rising schedule of registration fees may be secured for solid-tired vehicles by using a higher coefficient for the last term in the formula.

ADMINISTRATION

The tax schedule.—For administration purposes the tax schedule plotted and represented by formulas in Figure 2 would appear as in Table 1. In this table vehicles are divided into groups according to their gross weights and the registration fee for each group as determined by the formula is listed for convenient reference. It will be noticed that practically all of the passenger cars, except busses, fall in the first two groups, greatly simplifying the administration of fees for this most numerous class of vehicles.

Examples of the total annual taxes which will be paid by typical vehicles traveling 6,000 miles per year and

paying the six-cent fuel tax and the registration fees in Table 1 are as follows:

Gross weight of car in tons	Total annual tax
2	$26.60
4	56.70
7	118.10
11	231.30

Fixing taxable gross weight.—The actual gross weight of a vehicle, of course, varies with the number of passenger or the quantity of goods carried and also depends on the character of the equipment and the amount of fuel, oil, and water in the tanks. It is therefore necessary for the State to designate what the taxable gross weight of any given vehicle will be.

Three general methods of fixing vehicle weight are used at the present time. These methods are as follows: (1) A table giving weights for the various makes and models of cars is adopted by the State as official; (2) a certificate of weight from a licensed public weigher is required by the State to accompany the application for registration; (3) the weight as declared by the applicant is accepted by the State.

The most popular and probably the most convenient method of fixing the taxable weight of passenger cars is by means of a table, prepared or adopted by the State, which gives the gross weight of each make and model of car and such other data as the year, body style, number of cylinders, etc., as would aid in identifying a car in the table. The gross weight given in the table should be the sum of the vehicle weight as furnished by the manufacturer plus a seating capacity times an estimated average weight per passenger of perhaps 125 or 150 pounds.

The vehicle weight without passengers of homemade cars, nonstock models, and cars not listed in the table should be determined by actual weighing, and the application for registration of such vehicles should be accompanied by a certificate of weight from a licensed public weigher. Any owner who wishes to have his car weighed and submit a certificate of weight in preference to accepting the vehicle weight for his car as listed in the State's tables should be permitted to do so.

The taxable gross weight, once determined for a car, should be printed on the registration card, and subsequent registrations of the same car could be made on the basis of the original weight, provided no changes had been made in weight or tire type.

The many variations in the weights of commercial vehicles, due particularly to the wide variety of body types, makes it impracticable to make a table of gross weights of commercial cars.

Several jurisdictions now require that certificates of vehicle weight accompany the applications for registration of such vehicles. To the vehicle weights thus fixed, the carrying capacities are added to give the taxable gross weights.

A simpler method would be to accept the declaration of the owner as to the weight of his empty vehicle and the weight of the greatest load he expects to carry, the sum of the two weights being the taxable gross weight. The declared capacity of a vehicle should not be greater than the maximum nor less than the minimum stated by the manufacturer and the gross weight should not exceed that specified in the laws regarding tire width and thickness. The vehicle weight, capacity and gross weight as declared should be painted on the vehicle where they can be readily seen. The strict enforcement of a law prohibiting the loading of a vehicle so that its gross weight exceeds the registered gross weight would discourage understatement of weight by the owner.

CONCLUSIONS

The general adoption of some simple formula such as that suggested would result in more logical and equitable relations between taxes and the justifications for taxing, and between the fuel tax and registration fees than exist at present in the schedules of most of the States. Moreover, it would provide for uniform basic methods of rating vehicles and collecting fees throughout the country, at the same time permitting the several States to select schedules suited to their individual requirements.

APPENDIX A

FIXING THE CONSTANTS IN THE FORMULA

As has already been stated, three sets of corresponding values of tax and gross weight which will indicate the general trend desired in the tax-gross weight relation will serve to fix the constants A, B, and C in the formula.

However, at present there is no generally accepted method for determining the most equitable relation between tax and gross weight or, in this case, for fixing the three sets of values. Their proper evaluation is therefore likely to be the subject of much speculation and debate. They can, of course, be chosen more or less arbitrarily, but the most equitable choice will be assured only by a carefully conducted investigation.

Such an investigation would be concerned first with the determination of the relative costs to the State due to the operation of average vehicles of different gross weights, and second with a consideration of the relative economic and social desirability of the different weight vehicles as units of transportation. Taken together these two factors would fix the justification for taxing corresponding to each gross weight. Taxes could then be made proportional to the justification for taxing.

Gross weight and total tax.—Table 2 outlines one method of determinating quantitatively the equitable average relation between gross weight and tax. The cost to the State due to the operation of motor vehicles D should be estimated by adding the average annual costs over a period of several years of the items E, and F. The item E covers all administrative costs, including registration of vehicles, policing and regulation, signs and traffic devices, and departmental overhead. F is the sum of G and H and includes all highway costs. G represents the costs of constructing, rebuilding, or improving highways, while H represents the costs of patching, repairing, or treating roadways in such manner as to maintain them in proper condition.

The total number of vehicles registered for the average year, I, is divided into three convenient groups according to gross weight, and the number of vehicles in each group (a, b, and c), is recorded.

Administration costs, since they are independent of weight, can be equitably divided equally among all the vehicles in the State, each vehicle being charged with an amount equal to $\frac{E}{I}$.

TABLE 2.—*Outline of a method for determining the equitable total annual taxes for vehicles of different gross weights*

			Total number of vehicles	Total admin. costs	Total constr. costs	Total maint. costs	Total highway costs		Total cost to State	Total revenue required		
			I	E	G	H	F		D	P		
Group	Gross weight, tons		Number of vehicles in group	Administration cost per vehicle	Highway costs				Total cost per vehicle	Tax per vehicle on basis of cost to State alone	Desirability factor	Tax per vehicle modified according to desirability
	Range	Average			Construction	Maintenance	Total	Cost per vehicle				
1	Up to 3	d	a	$\frac{E}{I}$	G_1	H_1	F_1	J	M	Q	T	X
2	3 to 6	e	b	$\frac{E}{I}$	G_2	H_2	F_2	K	N	R	U	Y
3	6 to 15	f	c	$\frac{E}{I}$	G_3	H_3	F_3	L	O	S	V	Z

The difficult and uncertain part of the problem is the distributing of highway costs among the several groups of vehicles in such a manner that each will be charged with that portion for which it is responsible.

Roads designed to carry 3-ton vehicles without undue deterioration would be satisfactory for about 95 per cent of the vehicles in use to-day. To accommodate $\frac{4}{5}$ of the remaining 5 per cent, roads of double this strength would be required, while to be correspondingly safe for the heaviest group, weighing up to 15 tons and constituting about 1 per cent of the total number of vehicles, roads from three to five times as strong would be necessary. In practice, a road of normal design for general traffic will carry, without undue damage, a limited number of the heaviest vehicles now permitted by State laws, and it is only those highways that are used by a considerable number of the heavy vehicles that must be especially designed for their use. However, the additional costs of the stronger roads, where they are built, and any excessive maintenance costs of the lighter roads, where the stronger ones are not provided, are directly chargeable to the relatively small number of heavy vehicles.

In addition, these same heavy vehicles occupy more road space and require considerably wider roads, thus further increasing their share of highway costs.

Of course, costs justified by the size of a vehicle will not be distributed exactly as desired if based on gross weight. Vehicles which are very large but not correspondingly heavy will be undertaxed, while very heavy vehicles of relatively small over-all dimensions will be overtaxed. The few cases of this kind which occur, however, do not warrant the complication of the tax system by including vehicle size as a separate factor.

Distribution of construction and maintenance charges, to be most equitable, should be based on experimental data as to the relative destructiveness of vehicles of different weights on the various types of road. If the average annual mileage covered, the types of road most used, and the amount of traffic encountered are very different for the average vehicles of the different groups, then these factors might also be assumed to vary with weight in the distribution of charges.

In the quantitative apportionment of costs G_3 would be that part of G which could have been saved had there been no vehicles weighing more than 6 tons. In other words, G_3 is the amount expended in building into the roads the necessary extra strength and width to carry the heaviest group of vehicles. In a similar manner an additional amount, G_2, could have been saved had there been no vehicles weighing more than 3 tons, and G_2 is therefore chargeable solely to those vehicles which exceed this weight. G_1, then, is the expenditure for construction which would have provided equivalent improvements had all cars weighed 3 tons or less.

The maintenance costs are divided in like manner. H_1 is the cost of those repairs which would be expected had all vehicles weighed 3 tons or less. H_2 represents the additional damage done by vehicles weighing betwen 3 and 6 tons and H_3 is the amount chargeable solely to the heaviest group of vehicles.

The G and H values should be added to obtain the total highway charges.

F_1, the cost of constructing and maintaining roads for the lightest vehicles, should be divided equally among all vehicles in the State. Therefore $J=\frac{F_1}{I}$. The vehicles in Group 2, together with those in Group 3, should, in addition, be charged with the cost F_2, or $K=J+\frac{F_2}{b+c}$. The vehicles in Group 3 are charged with their share of F_1 and F_2, and in addition F_3 is divided among them solely. Therefore $L=K+\frac{F_3}{c}$.

The total costs to the State per vehicle for vehicles in each of the three groups are M, N, and O and are obtained by adding the administration cost per vehicle, $\frac{E}{I}$, to J, K, and L, respectively.

Special taxes can be made proportional to the total costs per vehicle. As mentioned before the State must fix the total revenue to be collected by means of special motor-vehicle taxes. In Table 2 this total revenue is represented by P. The tax per vehicle should bear the same relation to the cost per vehicle as the total revenue bears to the total cost to the State, or

$$\frac{P}{D}=\frac{Q}{M}=\frac{R}{N}=\frac{S}{O}$$

It is evident from the foregoing discussion that the number of vehicles in a given weight class is an important factor in determining the cost per vehicle. Up to the present time heavy vehicles have been relatively scarce and it is quite possible that taxes on these vehicles, figured on a basis of cost to the State alone, would be prohibitive at the present time. It should be realized, however, that large trucks and busses are built in response to a demand for vehicles which will transport large loads efficiently. A single large truck or bus will

carry the load of six or seven small vehicles at a much lower cost per mile and it will occupy less road space and often cause less traffic congestion than the numerous vehicles which it replaces. On account of these advantages, large vehicles are becoming increasingly popular and numerous in the more thickly populated sections. If the number of heavy vehicles continues to increase, if their loads are distributed on six or more wheels equipped with pneumatic tires, and if methods of constructing highways are improved and cheapened, it is quite probable that at some future time the cost per vehicle for this class will be considerably less than at present. For these reasons, prohibitive fees would be highly undesirable.

If it is thought that the cost to the State should not be the only criterion for determining the relation between gross weight and tax, modified taxes (X, Y, and Z) may be obtained by multiplying the values (Q, R, and S) by appropriate "desirability factors" (T, U, and V).

The amounts X, Y, and Z are the taxes which would apply on vehicles whose gross weights are the average gross weights (d, e, and f) of the three groups. The average for each group is obtained by adding the gross weights of all the vehicles in the group and dividing the sum by the number of vehicles in the group.

The three sets of corresponding values of tax and gross weight (X, d), (Y, e), and (Z, f) indicate the trend of the desired equitable relation between gross weight and tax and may be used to evaluate the constants in the formula for total annual tax, as follows:

$$C=\frac{(Z-Y)(e-d)-(Y-X)(f-e)}{(f^2-e^2)(e-d)-(e^2-d^2)(f-e)}$$

$$B=\frac{(Y-X)-C(e^2-d^2)}{e-d}$$

$$A=X-Bd-Cd^2$$

The fact that an effort has been made to tax each vehicle in proportion as that vehicle is responsible for expenses to the State should not be misconstrued as a suggestion that motor vehicles should pay these expenses in full. In practice, the total revenue required from special motor-vehicle taxes (P, Table 2) may be only a small fraction of the total cost to the State (D, Table 2), the difference being paid in general taxes. This is especially true when "desirability factors" differing considerably from unity are thought advisable. In this case the decrease in taxes on the favored classes of vehicles should be compensated for by a low value of P rather than by excessive taxes on the other classes of vehicles.

Fuel tax and registration fees.—The general formula with the numerical values of A, B, and C as determined above represents the total annual tax per vehicle. It would also represent the equitable registration fees for cars traveling the average number of miles per year, if no fuel tax were imposed. Thus, it might logically be used to determine registration fees on electric vehicles which escape the fuel tax. However, in order to distribute taxes fairly, not only according to gross weight but also according to miles traveled, it is most equitable to collect the largest possible portion of the total tax in the form of a fuel tax.

From data on the fuel consumption of a number of different cars it is estimated that fuel taxes distribute themselves among the average gasoline-driven cars of different weights approximately according to the following general formula:

$$\text{Annual fuel tax} = A + B \times (\text{gross weight})$$

where $A = 0.0834 \times$ (annual mileage in thousands of miles) $\times$ (fuel tax in cents per gallon); and $B = 0.314 \times$ (annual mileage in thousands of miles) $\times$ (fuel tax in cents per gallon).

The straight lines showing fuel tax in Figure 2 were obtained from this formula by assuming an average annual mileage of 6,000 miles and various values for the fuel tax in cents per gallon. If, now, the total tax curve (as plotted from the previously determined formula for total tax) is superimposed upon such a fuel tax chart, the most equitable fuel tax is at once apparent. It is the highest fuel tax which can be imposed, without eliminating registration fees entirely on one or more groups of vehicles, and it will be represented by a line just slightly below the total tax curve, as illustrated by the 6 cent line in Figure 2.

The formula for registration fees is now obtained by subtracting the formula for the most equitable fuel tax from the formula for total tax, as explained before.

Registration fees and tire type.—It is fairly well established that solid tires are more destructive to roads than pneumatic tires on a similar vehicle. Just how much more damage they do and just how the ratio changes with the weight of the vehicle or the type of road are not definitely known. However, a somewhat higher tax for solid tires is certainly justified. Since tires have little effect on fuel consumption, the difference must be made in the registration fee.

It is probable that the difference in destructiveness between solid and pneumatic tires is most noticeable in the heavier cars. Therefore a schedule which gives a gradually increasing difference in tax for the heavier vehicles is probably most equitable. Such a schedule can be obtained from the recommended formula by using a higher value of C for solid tired vehicles than for those on pneumatic tires.

Registration fees and number of axles.—When this paper was first written, no recommendations were made in regard to multi-axle vehicles. However, in the past few years vehicles having their weight distributed on three or more load-carrying axles and six or more wheels have increased in number, and since such vehicles are less destructive to roads than four-wheel vehicles of the same gross weight, a reduction in tax for this type appears to be justified. Since the fuel tax does not favor multi-axle vehicles, this reduction must be made in registration fees. A reduction which increases in amount for the heavier vehicles will be most equitable and may be secured, if desired, through the use of a lower value of C in the formula for registration fees.

Obtaining the desired total revenue.—Up to this point the discussion has dealt chiefly with the proper relative distribution of taxes. It may also be necessary to adjust the level of the whole system up or down to produce the required total revenue without changing the relative distribution. The income to be expected from a prospective system should therefore be estimated as closely as possible and the formula for total tax should be multiplied by the proper constant to increase or decrease the total tax per vehicle to the desired amount. From the new formula for total tax thus obtained, the amount of fuel tax and the constants for the registration fee formula must be redetermined.

APPENDIX B

OTHER SYSTEMS CONSIDERED

Early in this investigation the existing methods of determining motor vehicle registration fees were examined. None of these possessed all of the desired requirements. Several other possible methods were devised and rejected before the one described was finally selected as the best available in view of the conflicting requirements of equity, simplicity and adaptability. The limitations of the other systems studied will be discussed in detail. Although the fees and vehicle characteristics used as examples were taken from the tax schedules and vehicle specifications of several years ago they apply, in principle at least, to conditions existing to-day, and are therefore submitted as they were originally prepared.

Gross weight.—States basing registration fees on gross weight generally classify vehicles into groups according to gross weight and impose either arbitrary fees or arbitrary rates per ton or pound for the different groups. An example of an arbitrary schedule of fees is given in Table 3 and shown graphically in Figure 3. Such arbitrary schedules, whether based on gross weight or some other vehicle charactertistic, are likely to show erratic and apparently illogical variations in the rate per ton, and frequently increase by steps which seem excessive or out of proportion to the use of the roads. In the example a vehicle weighing 12,000 pounds pays a fee of $22.50, or about $0.19 per 100 pounds. Another vehicle only a few pounds heavier will have to pay more than three times this fee, or a rate of $0.62½ per 100 pounds, the same as that required for a vehicle of 24,000 pounds gross weight.

TABLE 3.—*Typical arbitrary schedule of fees based on gross weight*

Gross weight in pounds	Fee
5,000 or less	$12.00
Over 5,000 to 12,000	22.50
Over 12,000 to 16,000	75.00
Over 16,000 to 20,000	100.00
Over 20,000	150.00

Table 4 and Figure 4 show a typical system where arbitrary rates rather than arbitrary fees are imposed. This system is an improvement over the arbitrary fee system because rates are more likely to be consistent and differences between successive fees are usually small.

The need for a formula which would be flexible and yet impose gradually changing fees and consistently varying rates automatically regardless of the constants used, led to the selection of the general formula recommended in this report.

Carrying capacity.—If gross weight is accepted as the best single measure of the justification for taxing vehicles—and it is believed that it should be so accepted—then any other characteristic will be a good measure of the justification for taxing only in so far as it is proportional to gross weight. Capacity is only a part of gross weight and in present-day vehicles is only roughly proportional to gross weight.

Figure 5 shows graphically how trucks of given capacities vary in gross weight. For example, different makes of 4-ton trucks vary from less than 7 tons to nearly 10 tons in gross weight. In spite of this 6,000 pounds variation in weight, all makes would pay the same fee if rated according to capacity.

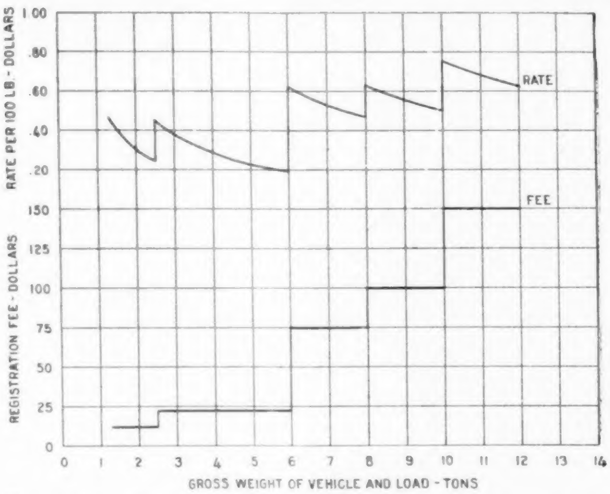

FIGURE 3.—TYPICAL ARBITRARY SCHEDULE OF FEES BASED ON GROSS WEIGHT

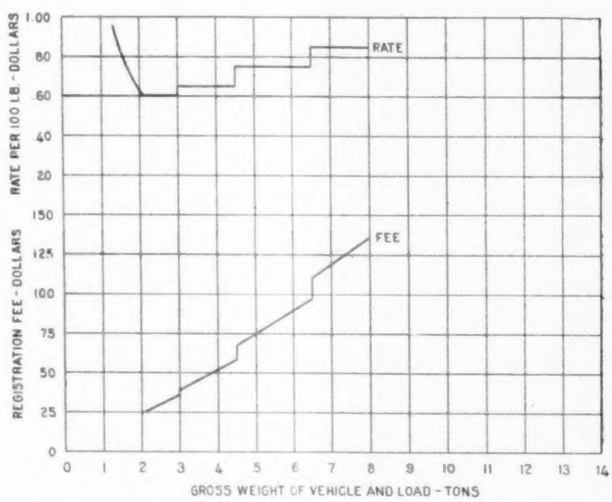

FIGURE 4.—TYPICAL ARBITRARY SCHEDULE OF RATES

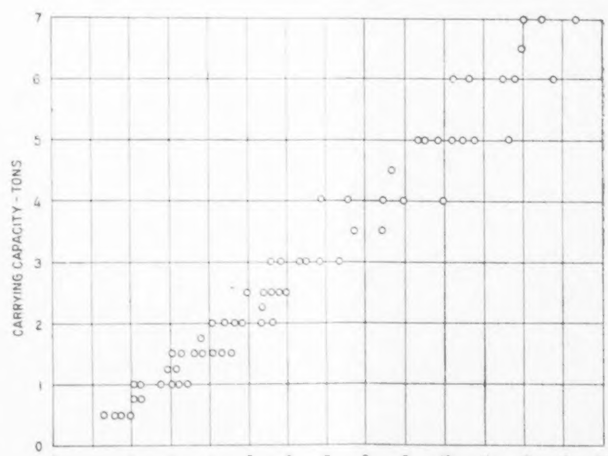

FIGURE 5.—GROSS WEIGHTS AND CARRYING CAPACITIES OF TYPICAL COMMERCIAL VEHICLES

It will also be noticed that the heavier trucks of one capacity frequently weigh more than the lighter

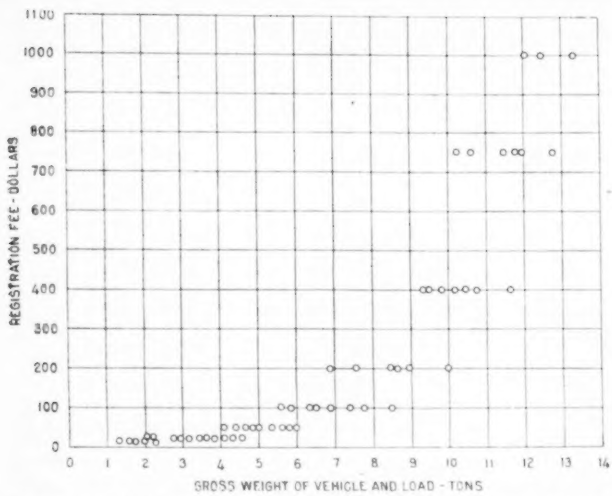

FIGURE 6.—EXAMPLE OF COMMERCIAL VEHICLE FEES BASED ON CARRYING CAPACITY

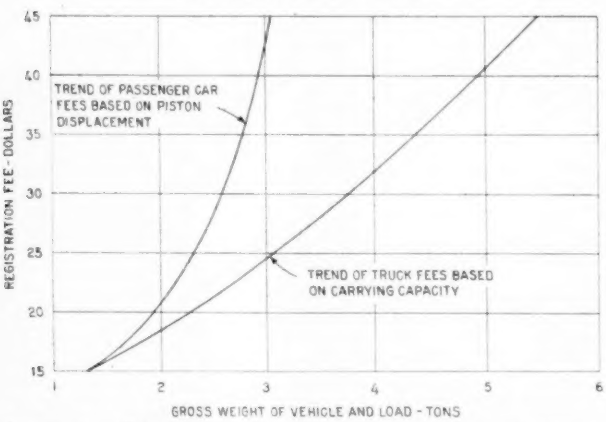

FIGURE 7.—EXAMPLE OF USE OF DIFFERENT CHARACTERISTICS FOR RATING PASSENGER CARS AND COMMERCIAL VEHICLES

FIGURE 8.—GROSS WEIGHTS AND CHASSIS WEIGHTS FOR TYPICAL COMMERCIAL VEHICLES

trucks of the next higher capacity. Thus, the heaviest 5-ton truck listed weighs 23,250 pounds when fully loaded, while the lightest 6-ton truck weighs only 20,450 pounds when fully loaded. Registration will

TABLE 4.—*Typical arbitrary schedule of rates*

Gross weight in pounds	Rate in cents per 100 pounds
6,000 or less	60
Over 6,000 to 9,000	65
Over 9,000 to 13,000	75
Over 13,000	85
Minimum fee, $25.	

cost this 6-ton truck $350 more in one State and in eight other States at least $100 more than it will cost the 5-ton truck in spite of the fact that the 6-ton truck weighs nearly 3,000 pounds less when loaded and nearly 5,000 pounds less when empty and, therefore, does less damage to the road than the 5-ton truck. Similar inconsistencies occur throughout the whole range of capacities and weights, as shown in Figure 6. A rating which imposes a heavy penalty on 2,000 extra pounds of carrying capacity and neglects entirely variations in vehicle weight of 6,000 pounds is obviously a poor measure of the justification for taxing.

From the viewpoint of economical transportation, it is desirable that vehicles be so designed that their weights empty are a minimum and their carrying capacities a maximum. Basing taxes on capacity tends toward the opposite condition. It discourages large capacities and at the same time fails to penalize overweight vehicles for their inefficient design.

If capacity is used as a basis for taxing trucks, then some other basis must be found for taxing passenger cars. The use of two separate bases is likely to lead to a seemingly illogical discrimination between passenger cars and trucks. Figure 7 illustrates this point graphically. Here passenger-car fees are based on piston displacement and increase rapidly with gross weight. Truck fees are based on capacity and increase much more slowly. The result is that while the lightest passenger cars and trucks pay about the same fee, the heaviest passenger cars pay nearly twice as much fee as trucks of the same weight and the same fee as trucks of nearly twice their weight. In some other States the situation is reversed, and trucks pay the higher fees. For convenience, uniformity, and equity, taxes on all vehicles should be based on the same characteristic.

Chassis weight and unladen weight.—Like the capacity, the chassis weight or the unladen weight of a vehicle constitutes only a part of the gross weight imposed on the roadway. As shown in Figure 8, there is a wide variation in the gross weights of trucks of approximately the same chassis weights. There is a somewhat similar variation in the gross weights of vehicles having approximately the same unladen weights. Therefore, fees will be improperly distributed if based on either of these characteristics.

Figure 9 illustrates the result of basing truck fees on chassis weight. Truck A, with a capacity of 7½ tons, pays the same fee as truck B, with a capacity of only 3 tons, in spite of a difference of nearly 6 tons in their gross weights. Truck C pays twice as much as truck D, although their gross weights are approximately the same, and truck C also pays $75 more than truck A, although truck A is 3 tons heavier when loaded. It is perhaps desirable to tax vehicle weight at a higher rate than pay load, but such excessive penalties as are sometimes involved in the basis of truck fees on chassis weight or unladen weight seem unjustified.

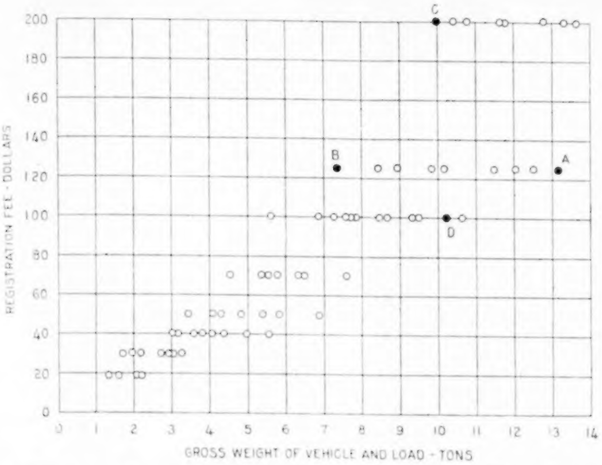

FIGURE 9.—EXAMPLE OF COMMERCIAL VEHICLE FEES BASED ON CHASSIS WEIGHT

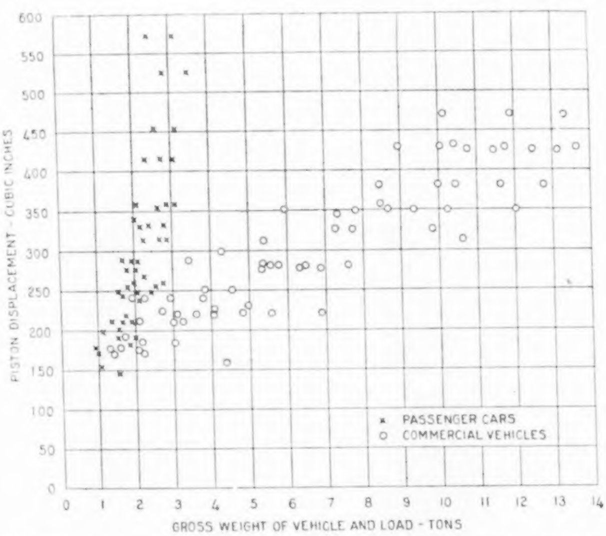

FIGURE 10.—GROSS WEIGHTS AND PISTON DISPLACEMENTS FOR TYPICAL VEHICLES

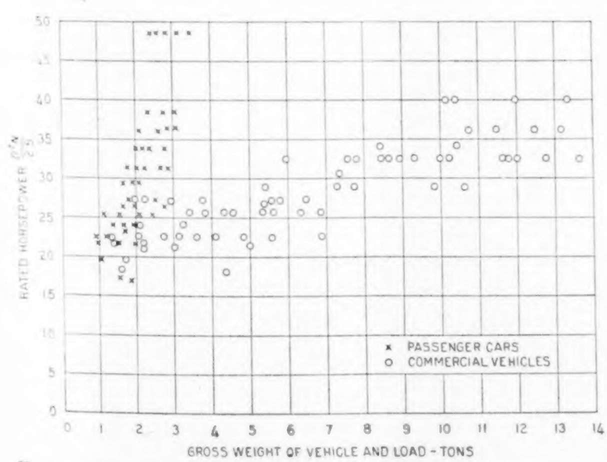

FIGURE 11.—GROSS WEIGHTS AND RATED HORSEPOWERS OF TYPICAL VEHICLES

The same criticisms apply to a lesser degree to unladen weight as a basis for taxing passenger cars. Small passenger cars of the same unladen weight have differences in carrying capacity of 3 to 5 persons causing variations in gross weight of about 20 per cent, while the situation for large busses is much the same as for trucks.

Tire width.—When the weight allowed on a wheel or axle is limited by law according to the width of the tires used, tire width tends to become a rough measure of gross weight and may be used as a basis for determining fees.

Tire width seems to have no marked advantages over gross weight as a basis for taxing, but it possesses some disadvantages. If adopted generally, schedules would have to be devised which would distribute taxes equitably among vehicles equipped not only with solid tires but with high-pressure pneumatic and the various classes of balloon tires as well. Such taxes would encourage owners and makers of vehicles to use the minimum width of tire allowed, and those vehicles which used wider pneumatic tires than this minimum would be penalized by the tax in spite of the fact that their equipment was particularly good as regards protection of the highway.

Rated power.—Engine power is available either for moving weight or producing speed, both of which damage the road. Speed, however, for the very great majority of cars is limited not by the power of the engine but by law, by road and traffic conditions, or by the whim of the driver. In States where traffic is relatively dense, it seems probable that the average speed of high-powered cars would differ little from the average speed of low-powered cars, and vehicles which move more slowly than the average speed for all traffic are perhaps as objectionable as those which travel somewhat faster than the average. The value of power as a measure of use of the roads will therefore depend more on its proportionality to gross weight than on its rather doubtful relation to speed.

At present, no power rating available gives values of power which are even approximately proportional to gross weight. Figures 10, 11, and 12 show wide variations in the power ratings of passenger cars of essentially the same gross weight, and great divergence in the weight of trucks of approximately the same power.

An example of the effects of basing passenger-car fees on horsepower is shown in Figure 13. There is a car weighing approximately 4,000 pounds in each of the four fee groups shown. These four cars pay fees of $12.50, $20, $30, and $40, respectively, supposedly because their engines are capable of propelling them at different speeds. As a matter of fact, their average speeds and their use of the roads are probably nearly the same. Among those cars which pay a $20 fee is one which weighs only 2,200 and another which weighs 5,500 pounds.

Figures 10, 11, and 12 show how rapidly the power of passenger cars increases with weight and how slowly the power of trucks increases. Obviously the same schedule of fees would not be applicable to both classes. Also, if gasoline cars are to be rated on formula horsepower or piston displacement, different ratings must be used for steam vehicles, for electric vehicles, and for trailers. Taxing each of these classes on a different basis would be almost certain to lead to inconsistencies between the various schedules and discrimination between vehicles in the different classes whose use of the road is approximately the same.

Another difficulty in the use of power as a basis for taxing is that the various power ratings disagree. For

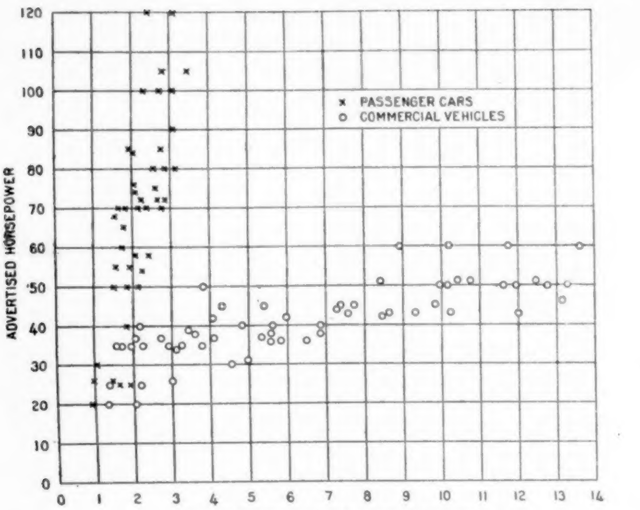

FIGURE 12.—GROSS WEIGHTS AND ADVERTISED HORSEPOWERS OF TYPICAL VEHICLES

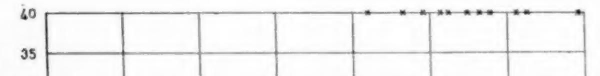

FIGURE 13.—EXAMPLE OF PASSENGER CAR FEES BASED ON RATED HORSEPOWER

example, car A has a formula horsepower 17½ per cent greater than that of car B, a piston displacement 47 per cent greater and an advertised horsepower 325 per cent greater. What, then, is the relation on which taxes should be based?

***Price and value.*—There is, very obviously, no direct relation between the price of a vehicle and its use of the roadways. The only justification for using price as a measure of such use is the remote relation which price happens to bear to gross weight. This relation is shown in Figure 14 and is evidently entirely too remote to provide an equitable basis for taxing. The chart is somewhat similar to those showing the relation**

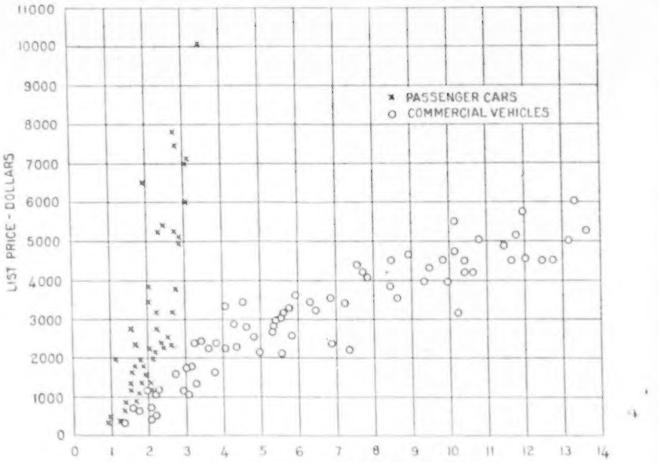

FIGURE 14.—GROSS WEIGHTS AND LIST PRICES OF TYPICAL VEHICLES

between power and gross weight. The average price of passenger cars increases very rapidly with gross weight, while the average price of trucks increases very slowly. A single schedule of fees based on price would therefore not be applicable to both passenger cars and trucks nor would the distribution among units of the same class be equitable because of the wide variation in the prices of passenger cars of approximately the same gross weight and the great divergence in the weights of trucks of approximately the same price.

Value is even more illogical and unsuited as a basis for special taxing. It is odd to conceive of a new truck in perfect mechanical condition and equipped with new tires, being charged with a greater highway expense than an old truck with tires worn down near the legal limit of thickness and mechanical condition a menace to the safety of the public.

Flat rate.—This form of tax is evidently very unfair to the smaller vehicles as it puts as much of a burden on the lightest as on the heaviest cars. Where it is used the gas tax is sometimes expected to correct for the inadequacy of the registration fees on the heavier cars. As explained previously, no fuel tax can do this where an increasing rate or fee per ton is desired.

Combination ratings.—Some States use capacity, unladen weight, power, or value in combination with each other or with gross weight in rating vehicles. The criticisms which apply to the use of these characteristics singly apply also to their use in combination. The use of any of them in connection with gross weight impairs rather than improves the fairness of the gross weight rating and at the same time complicates its administration.

A METHOD OF ANALYSIS OF DATA ON FROST OCCURRENCE FOR USE IN HIGHWAY DESIGN

By J. A. SOURWINE, Senior Highway Engineer, U. S. Bureau of Public Roads

A FEW years ago frost occurrence presented only a minor highway problem. To-day it has become a major problem. Improved facilities for snow removal keep open an increasing highway mileage. Winter traffic is increasing also per unit of mileage. The annually increasing mileage of road left uncovered and unprotected from frost attack makes frost occurrence a highway problem which deserves intensive study.

These facts suggest the question: May frost occurrence and highway frost damage be so interrelated as to make possible the use of existing climatological records as a means for assisting in the determination for a given locality of the probability of occurrence of highway frost damage?

This paper presents a method by which we may so relate and summarize recorded climatic occurrence as to render usable for highway design the records of past weather conditions as a guide in the determination of probable ground freezing occurrence. This study does not consider the problem of freezing weather during the construction period. Nor does it consider the problem of the modifying effect on ground freezing, due to type of soil, to degree of compactness of soil, to varying moisture content in soil, to topographic placement, or to the presence of surface cover which affords continuous shading from the sun. There is considered rather the intensity duration and frequency of low temperature occurrence over a period of years, seeking to develop a method by which climatological records may be made available as a guide in the determination of relative probable highway damage. The determination reached will be relative only, based on the temperature occurrence phase of the ground freezing problem and subject to modification as applied to any local area to meet the actual modifying conditions there existent.

Let us first consider what portion of existing temperature records is most suitable as a basis for comparison to determine the probable relative danger of highway ground freezing for any given location. There seems to be doubt as to the suitability of absolute minimum temperatures[1] for such use. As an illustration, the lowest absolute minimum temperature recorded for Washington, D. C., is −15° F. As a basis for comparison this extreme low minimum temperature does not appear truly typical or as offering a basis suitable for use in highway design for Washington, D. C. The indication is that other modifying factors should also be considered. One of these modifying factors is the relative frequency of low temperature occurrence.

About six years ago the United States Weather Bureau prepared for the Bureau of Public Roads two isothermal charts of the United States, one showing isothermals of normal temperature and the other showing isothermals of average minimum temperature for the month of January. These charts were based on records computed to the end of the year 1914. They represent the existing data available in the files of the United States Bureau of Public Roads on temperature records as affecting highway design in the United States.

A study of summarized climatological data for the United States, taken from Bulletin W of the United States Weather Bureau, shows that January is not always the month of extreme cold, the actual month varying for different localities and even for different years in the same locality, but being in general one of the three months, December, January, or February. In order to establish a common basis for comparison of the relative intensity of low-temperature occurrence in different localities, we will use the records of each observing station for the most severe winter month at that station. The lowest monthly average of daily minimum temperature over the period of record covered by Bulletin W (being in general from the beginning of available record to and including the year 1921) is used as a basis for this comparative study of low-temperature intensities.

CRITICAL INITIAL AIR TEMPERATURE FOR GROUND FREEZING SELECTED AS 23° F.

Before proceeding further we must determine the average critical initial air temperature at which, under conditions of descending air temperature, highway ground freezing occurs. A careful study has been made to determine this critical initial air temperature. Laboratory tests are available, by A. Petit,[2] and by Geo. J. Bouyoucos,[3] in which there was investigated the required lowering of air temperature, in order to produce freezing in soils. The results found by Petit and by Bouyoucos are closely similar. The degree of supercooling of air required varies according to the type of soil, from −4° C. to −5° C. The value found by Petit for an average clay is −4.8° C., or 23.4° F. Both the Petit and Bouyoucos tests show that a duration of supercooled temperature of from 2½ to 4½ hours is required in order to produce freezing in the soil. The period of duration of supercooling as found by Petit is 160 minutes for sand, 190 minutes for average clay, and 266 minutes for peat. For fine, silty clay of the type in which highway ground freezing frequently occurs, three and one-half hours is assumed as an average value of the period of duration of supercooling.

A study of the thermograph records[4] for a number of Weather Bureau stations of the first order located at widely scattered points over the United States shows that an absolute minimum air temperature very seldom endures for a period of three and one-half hours. The maintaining of a given effective low temperature, under conditions similar to a laboratory experiment, for three and a half hours is commonly accompanied, under actual

[1] Absolute minimum temperature is defined as the lowest temperature occurring during a given cold period.

[2] "Untersuchungen uber den Einfluss des Frostes auf die Temperature—Verhaltnise der Boden," by A. Petit, in "Forschungen auf den Gebiete der Agriculture—Physik," v. 17, p. 285-310.

[3] "Temperature which soils can reach without freezing," by Geo. J. Bouyoucos Journal of Agr. Res., November 15, 1920.

[4] Thermograph records for first order stations, U. S. Weather Bureau.

field conditions, by the occurrence of an absolute minimum air temperature, which is 1.5° F. to 2.0° F. lower than the effective temperature required to be maintained throughout the period. Applying this observed relation, together with the results of the laboratory tests by Petit and by Bouyoucos, on the supercooling of air required to produce soil freezing, we determine a critical initial minimum air temperature, for conditions of descending air temperature, at which the average subgrade soil lying in place under nonagitated conditions may be expected to begin to freeze. This critical initial value is from 23.0° F. to 23.5° F. for sand, from 21.4° F. to 22.4° F. for clay, and from 22° F. to 23° F. for fine sandy loams and silty loams. An air temperature of 23° F. is assumed as an average critical initial value marking the beginning of ground freezing in average highway subgrade soil. This value of 23° F. will be used throughout the remainder of this study as the critical initial value of descending air temperature below which the intensities, durations, and frequencies of frost occurrence will be studied and compared.

The next item for determination as a basic relation in our study is the critical depth below the surface of ground for average subgrade soil at which the occurrence of freezing will produce objectionable heaving or will cause unevenness or lack of stability in the highway surface. This critical depth would seem to be properly determined only on the basis of practical field experience. Inquiry was made accordingly. Several highway engineers expressed the opinion that 6 inches of ground freezing is a critical value and that at this depth ground freezing becomes objectionable, basing such opinions on the tendency of present-day design of pavement depths for first class pavements. Other highway engineers expressed a judgment favoring a 4-inch depth as critical, basing the conclusion on experience with lesser thicknesses of pavement and on conditions in surface-treated roads. For the purpose of this study a critical depth of 3 inches has been assumed as the depth below which ground freezing becomes a problem for consideration in highway design.

CRITICAL LOWEST MONTHLY MINIMUM TEMPERATURE FOR OBJECTIONABLE GROUND FREEZING DISCUSSED

In order to use the records of lowest monthly average of daily minimum temperatures as a basis for comparative study to determine the relative danger of highway ground freezing for any locality, we must determine the critical value of lowest monthly average of daily minimum temperature at which ground freezing occurrence passes the allowable frequency for 3-inch depth. As to what constitutes allowable frequency, we are faced with the necessity for an arbitrary assumption. For this study we assume an allowable frequency of 5 per cent. We define "5 per cent allowable frequency" to mean that when we consider for any locality all cold periods sufficient to cause freezing of average surface soil, ground freezing below 3-inch depth may occur 1 time in 20. A frequency of more than 5 per cent, or more than 1 period in 20, we designate as "objectionable frequency."

Let us now determine a tentative critical value of the lowest monthly average of daily minimum temperatures which corresponds with an average of 5 per cent frequency of occurrence of highway ground freezing to a depth greater than 3 inches. Reference is again made to the tests of Petit and of Bouyoucos, consideration being given this time, not to the supercooling of air, but to the supercooling of soil required before soil freezing will occur. The amount of supercooling of a nonagitated soil required for freezing is found to vary from −1.5° C. for sand to −2.0° C. for clay, with a required duration of three to four hours. This is equivalent to the requirement which is assumed as applying to soils ranging from fine silty clay loam to clay, that an effective soil temperature of 28.4° F. shall be constantly maintained over a period of three and one-half hours in order to produce objectionable soil freezing. In the study of United States Weather Bureau thermograph records of air temperature occurrence it has been found that for cold periods of three and one-half hours below a given effective temperature the absolute minimum temperature was on the average 2° F. below the maintained effective temperature. Assuming a similar relation to apply to soil temperatures as found for air temperatures, a minus correction of 2° F. is applied to the effective soil temperature of 28.4° F. above found, which gives a required absolute minimum soil temperature of approximately 26.4° F., coincident with the inception of ground freezing for the general type of subgrade soil in which troublesome ground freezing frequently occurs.

RELATION ESTABLISHED BETWEEN MINIMUM TEMPERATURE IN AIR AND THE SOIL

The next step is to establish a relation between average minimum air temperature and average minimum temperature in soil at a 3-inch depth. For the most complete investigation of this subject reference is made once more to Bouyoucos, and particularly to a series of field measurements conducted by him at East Lansing, Mich., during which he measured temperatures in air 4 feet above the surface and in ground 3 inches below the surface[5] throughout the month of

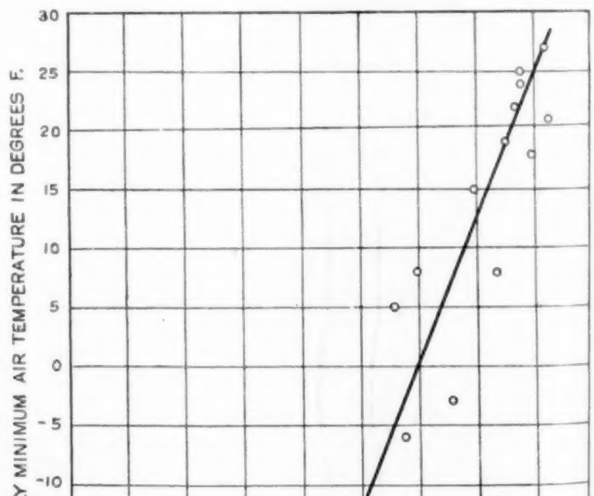

FIGURE 1.—DAILY MINIMUM SOIL TEMPERATURE AT 3-INCH DEPTH COMPARED WITH DAILY MINIMUM AIR TEMPERATURE, DURING A PERIOD OF DESCENDING TEMPERATURE

[5] "Soil Temperatures," by Geo. J. Bouyoucos Bulletin No. 26 Mich. Agr. Col. Exp. Station.

January, 1915. Daily minimum, maximum, and mean temperatures were observed and recorded during this test. For 16 days of the month the record shows a descending temperature. Figure 1 shows the minimum temperature in air compared with that in the soil at a 3-inch depth for each day of descending temperature during the month.

Through the points of actual occurrence, plotted in Figure 1, a line was drawn representing the average relation between minimum air temperature and minimum temperature in soil at a 3-inch depth. From this average line the average minimum air temperature, which is equivalent to a soil temperature of 26.4° F. at a 3-inch depth, is found to be 16° F.

FREQUENCY OF MINIMUM TEMPERATURES STUDIED

The above derived value of 16° F. is the actual average equivalent minimum air temperature at which ground freezing begins at 3-inch depth. At this minimum air temperature of 16° F. no allowable frequency of frost occurrence is permitted below 3-inch depth. We desire to use for design an allowable frequency of 5 per cent for frost occurrence below 3-inch depth. Let us study the existing relations and determine the absolute minimum air temperature at which 5 per cent of frost occurrence below 3-inch depth is permitted. For this study we select 15 first-order stations of the United States Weather Bureau, rather well distributed across the United States, so as to obtain typical data representative of the different sections of the country.

The stations selected are all located in regions classified as being in doubtful danger from ground freezing and are well distributed over the United States so as to obtain data representative of the different sections of the country. From the records of these 15 stations there were tabulated all periods where the temperature fell below 23° F. (critical initial air temperature assumed as required to produce freezing in average subgrade soil) for a duration of eight hours or more, and for a drop in temperature greater than 3° F. The tabulation showed the minimum temperature in degrees Fahrenheit for each cold period and the duration of cold period below 23° F. For four of the stations the record covered the 15-year period from 1907 to 1921 (for Tonopah, Nev., 14 years only, on account of no record for 1907 available). For the other 11 stations the record covered an 11-year period, from 1911 to 1921. These records were summarized to show frequency of cold period and low temperature occurrence, and a minimum temperature-frequency curve was plotted for each station. Typical curves showing the variation in frequency for varying minimum temperatures are shown in Figure 2. The ordinate of any point in Figure 2 denotes the relative frequency of occurrence of the absolute minimum temperature indicated by the abscissa. This relative frequency is expressed as a percentage of the total number of cold periods. As an illustration, in the case of Washington, D. C., the point on the curve for that station having an abscissa of 0° has an ordinate of 3 per cent, indicating that, of all cold periods occurring at Washington, D. C., for only 3 per cent of the number did the temperature go as low as 0° F. From the curve for each station a minimum temperature value is obtained corresponding to 5 per cent frequency, and from the available records the absolute minimum temperature reported during the period covered by the study is determined. Table 1 shows these two values and the average difference between them for each of the 15 typical stations.

TABLE 1.—*Minimum temperature of 5 per cent frequency occurrence versus absolute minimum temperature*

Station	Period of study	Minimum temperature with frequency of 5 per cent (1)	Absolute minimum temperature (2)	Difference (1)−(2)
		° *F.*	° *F.*	° *F.*
New Haven, Conn	11 years, 1911–1921	−0.5	−12.0	−11.5
New York, N. Y	do	+1.0	−14.0	−15.0
Philadelphia, Pa	do	+4.0	−4.0	−8.0
Washington, D. C	15 years, 1907–1921	+5.0	−13.0	−18.0
Elkins, W. Va	11 years, 1911–1921	−5.0	−28.0	−23.0
Lynchburg, Va	do	+4.0	−7.0	−11.0
Lexington, Ky	15 years, 1907–1921	−2.0	−14.0	−12.0
Nashville, Tenn	11 years, 1911–1921	+1.3	−10.0	−11.3
Evansville, Ind	do	−1.8	−16.0	−14.2
Cairo, Ill	do	−2.0	−15.0	−13.0
St. Louis, Mo	do	−3.5	−16.0	−12.5
Bentonville, Ark	do	−2.5	−20.0	−17.5
Oklahoma City, Okla	do	−0.5	−10.0	−9.5
Amarillo, Tex	15 years, 1907–1921	+1.0	−11.0	−12.0
Tonopah, Nev	14 years, 1908–1921	+5.0	−7.0	−12.0
Average				−13.37

CRITICAL VALUE OF LOWEST MONTHLY AVERAGE OF DAILY MINIMUM TEMPERATURE FOUND TO BE 23° F.

Since it was observed that one station (Elkins, W. Va.) in the table shows a difference considerably above the average and another station (Philadelphia) shows a difference somewhat below the average, an average value of difference was computed, excluding values for Elkins and Philadelphia, and was found to be 13.04° F. As a representative difference between absolute minimum temperature and minimum temperature of 5 per cent frequency occurrence, we will assume the value 13° F.

The air temperature at which ground freezing begins at 3-inch depth in average subgrade soil has been found to be 16° F. By applying to this value the average difference of 13° F. between absolute minimum temperature and minimum temperature for 5 per cent frost frequency, 3° F. is obtained as a critical absolute minimum air temperature coincident with 5 per cent frequency of ground freezing at a 3-inch depth.

By the use of data from the thermograph records of the four stations of which a 15-year study was made, Figures 3 to 5 were prepared showing the relation between the monthly average of daily minimum temperature and absolute minimum temperature for each station. A line was drawn in each instance representing the average location of these points. From this line there was obtained for each station the monthly average of daily minimum temperatures corresponding to an absolute minimum of 3° F. The results are as follows:

	° F.
Washington, D. C	24.2
Amarillo, Tex	24.4
Tonopah, Nev	23.3
Lexington, Ky. (graph not shown)	25.0
Average	24.4

The above is the monthly average of daily minimum temperature for the period of the thermograph study (15-year period 1907–1921). A tabulated comparison of lowest monthly average of daily minimum temperatures for the 15-year period compared with the lowest monthly average of daily minimum temperatures over the full period of United States Weather Bureau records is shown in Table 2.

Table 2 indicates that we should apply a correction of −2° F. to the lowest monthly average of daily minimum temperature for the 15-year period in order to obtain the lowest monthly average of daily temperature over the period of United States Weather Bureau

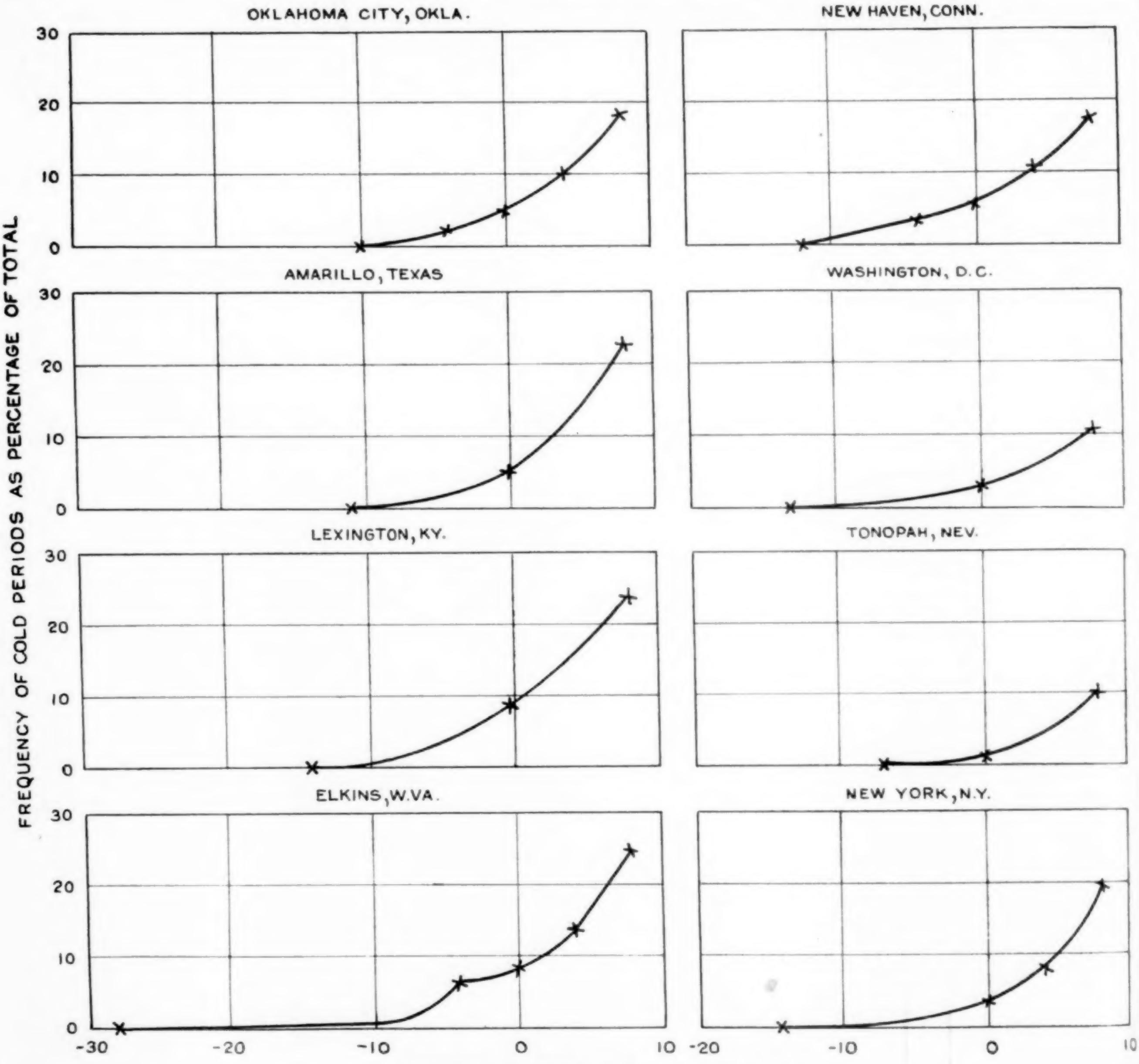

FIGURE 2.—MINIMUM TEMPERATURE-FREQUENCY CURVES FOR SELECTED STATIONS SHOWING RELATION BETWEEN MINIMUM TEMPERATURE OCCURRING WITH A FREQUENCY OF 5 PER CENT, AND ABSOLUTE MINIMUM REPORTED

TABLE 2.—*Relation between lowest monthly average of daily minimum temperature for 15-year period 1907–1921 compared with lowest monthly average of daily minimum temperature for total period of United States Weather Bureau records*

Station	Average for 15-year period	Average for total period of U. S. Weather Bureau records
	° F.	° F.
Washington D. C	25.4	25.7
Amarillo Tex	26.0	20.7
Tonopah Nev.[1]	24.0	24.1
Lexington Ky	26.2	23.2
Average	25.4	23.4

[1] 14-year record 1908–1921.

record. Since the study was based on a small number of stations and there was some difference in the variation shown by the different stations, approximately two-thirds the amount of the indicated correction will be applied, making a correction of − 1.4° F. With this correction applied, the critical value for monthly average of daily minimum temperature over the entire period of United States Weather Bureau record is determined as 23° F. This critical value of 23° F., for the lowest monthly average of daily minimum temperature, is assumed as a critical design value for highway ground freezing.

In the compilation of the temperature data shown in Figure 6 use was made of data from all stations for which the United States Weather Bureau has summarized temperature records prior to and including the year 1921.

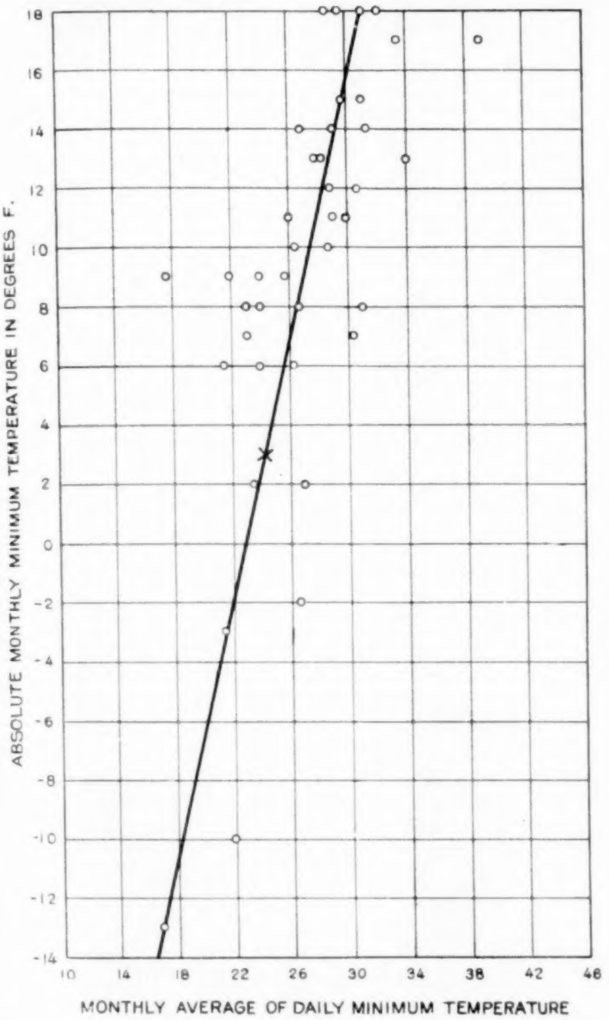

FIGURE 3.—RELATION BETWEEN MONTHLY AVERAGE OF DAILY MINIMUM TEMPERATURE AND ABSOLUTE MINIMUM TEMPERATURE AT WASHINGTON, D. C.

(Bulletin W, United States Weather Bureau.) An isothermal map was made for each State, and these maps were combined in Figure 6. On this map the isohyetal lines or lines of low average winter rainfall, indicating relatively arid regions, are taken from the Atlas of American Agriculture, United States Department of Agriculture. The rainfall shown is the average winter rainfall which occurred during three winter months, December, January, and February. All low average winter rainfall of 2 inches and less is shown. The areas with an average winter rainfall of 2 inches or less and within a zone having a lowest monthly average of daily minimum temperature between 10° F. and 23° F. are cross-hatched on Figure 6 as being areas which, because of their winter aridity and of their relatively moderate range of extreme cold, may be areas of doubtful danger from the standpoint of highway ground freezing. The presentation of these isohyetal lines marking arid regions with low winter rainfall is made to invite attention to this phase of climatic occurrence, with the suggestion that further more detailed study of these regions is advisable. The assumed temperature range of 10° F. to 23° F. is approximate only and subject to future modification as to proper lower limits of temperature range.

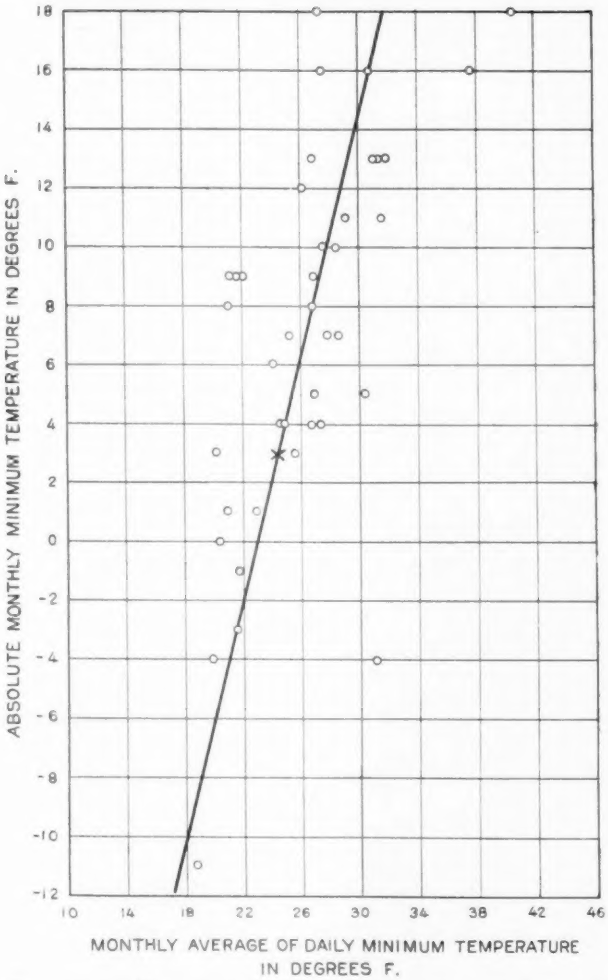

FIGURE 4.—RELATION BETWEEN MONTHLY AVERAGE OF DAILY MINIMUM TEMPERATURE AND ABSOLUTE MINIMUM TEMPERATURE AT AMARILLO, TEX.

Summarizing the preceding phase of the study, in which only low-temperature intensities and frequencies are considered and a 5° allowable frequency of ground freezing below 3-inch depth is assumed, the 23° F. isothermal shown in Figure 6 marks a general critical temperature line below which should lie areas relatively safe and above which should lie areas relatively dangerous from highway ground freezing. The critical temperature line thus shown and marked is a general line only based on the recorded intensity and frequency of low temperature occurrence applied to average highway conditions and subject to modification or approval for any local area as shown by detail study covering local conditions of soil, drainage, surface cover, and exposure.

DURATION OF COLD PERIODS AN IMPORTANT FACTOR

A further study has been made taking into account the duration phase of cold period occurrence. The effect of duration of cold period in accentuating and rendering more severe the damage from cold is a matter of common knowledge. It is well known that several days duration of low temperature, even with a rather moderate minimum temperature, may produce effects equally damaging and possibly even more damaging than those produced by a minimum temperature several degrees colder but having only a short duration. The problem has been to relate and express the different

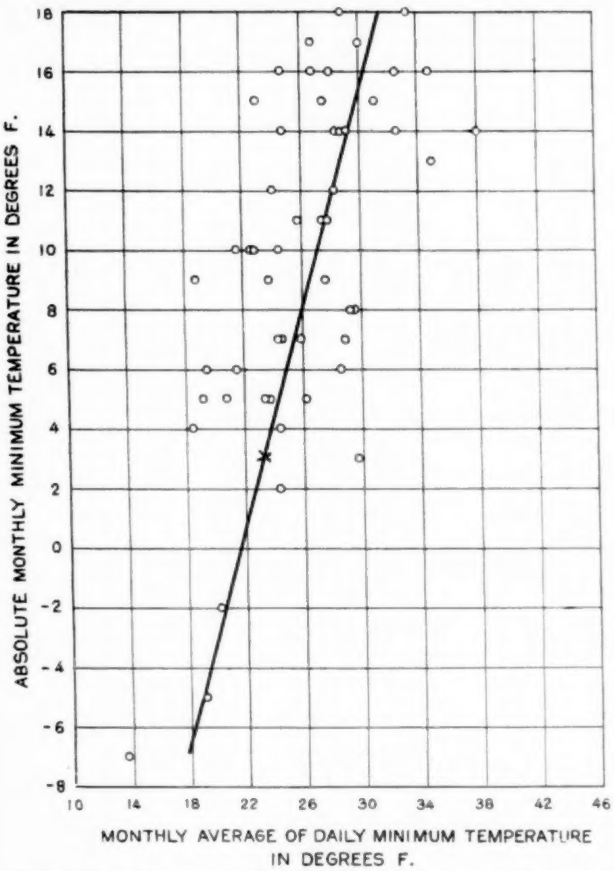

FIGURE 5.—RELATION BETWEEN MONTHLY AVERAGE OF DAILY MINIMUM TEMPERATURE AND ABSOLUTE MINIMUM TEMPERATURE AT TONOPAH, NEV.

variables of low-temperature intensity, frequency, and duration in such a way as to make possible a means of measuring the relative degree of their combined effect.

For the purpose of this study a method of measuring the combined effect of low temperature and of cold period duration has been worked out and applied as a means of comparative measurement of cold period occurrence for different periods and in different localities. The unit used for comparison is similar to the "ton-mile" so common in highway traffic terminology. The term used is "degree-hours." The degrees are measured in °F. below the critical initial air temperature and the duration is measured in hours of cold period below the critical initial air temperature. The approximate value of "degree-hours" for any given cold period is ½ D T, where D equals duration in hours below critical initial air temperature and T equals the degrees Fahrenheit of absolute minimum air temperature below critical initial air temperature. For this study the critical initial air temperature used is 23° F.

A "degree-hour" study of cold periods has been made, using data from 35 Weather Bureau stations lying in the general proximity of the tentative critical isothermal (23° F.) shown in Figure 6. The thermograph records from each of these stations, covering a period varying for different stations from 5 to 15 years, were studied. The first study covered a 5-year period, but this length of time was in general found to be insufficient to give a representative record. A study covering a 15-year period was then made for a few stations, and an 11-year period was studied for other stations located in critical positions, in determining the position of equal degree-hour lines. Five-year records from a few minor stations were also studied. All data were summarized according to frequency of occurrence both of relative duration of cold period and of relative minimum temperature of cold period. There was then plotted for each station a duration-frequency curve and a minimum temperature-frequency curve. From the two frequency curves thus plotted there was derived a third curve, the degree-hour-frequency curve (fig. 7).

As in Figure 2, the ordinate of any point in Figure 7 denotes relative frequency of occurrence expressed as a percentage of the total number of cold periods for the given station. For the minimum-temperature frequency curve the abscissa denotes absolute minimum temperature of cold period, as in the case of Figure 2. For the duration-frequency curve the abscissa denotes duration of cold period. For the degree-hour frequency curve the abscissa denotes degree-hours accumulated during cold period.

A measure of the quantity of cold occurring at each station was determined by selecting as an index the degree-hours corresponding to a frequency of 5 per cent, the numerical value being taken from the degree-hour-frequency curve. These degree-hour indices for the different stations were plotted on a map of the United States (fig. 8), which for convenience of identification has been called an "isothermo-chronal map." On this map, isothermo-chronal lines, or lines of equal "degree-hour-index" for 5 per cent frequency of occurrence, have been drawn. After considerable study, a degree-hour index of 900 was assumed as the critical isothermo-chronal, representing the danger line for highway ground freezing, based on the combined study of low temperature intensity, cold period duration, and cold period frequency. For convenient presentation of the variation in the "degree-hour" index with change in location, one isothermo-chronal on each side of the critical isothermo-chronal has been shown, the isothermo-chronals of 600 and of 1,200 degree-hours being used. It will be noted that this degree-hour index is very sensitive, changing greatly for relatively small differences of location, or of cold period occurrence.

INDEX MAP USED TO SHOW MOST ADVERSE CONDITIONS OF FROST OCCURRENCE, CONSIDERING THE THREE PHASES OF INTENSITY, FREQUENCY, AND DURATION

A comparison of the isothermal study as shown in Figure 6 and the isothermo-chronal study as shown in Figure 8 shows a considerable area in the eastern and central portions of the United States not indicated as dangerous for ground freezing by the 23° isothermal but which is definitely indicated as in danger of ground freezing, when considered from the combined standpoint of low temperature and of period of duration of cold. The Columbia River Valley in Washington and Oregon appears to offer a somewhat similar condition but the limited number of first-order Weather Bureau stations located in this region do not afford a basis for other than approximate location of isothermo-chronal lines. In the mountainous areas in northwestern Texas, New Mexico, Arizona, Nevada, eastern California, and western Oregon and Washington the number of first-order weather stations is relatively small. The data obtained from the few stations available show that most of the cold periods are of relatively short duration, and therefore the period of duration is not in general an important factor. In this region the critical isothermal is in general the line of demarcation between relatively dangerous territory and territory relatively safe, and isothermo-chronal lines are not shown

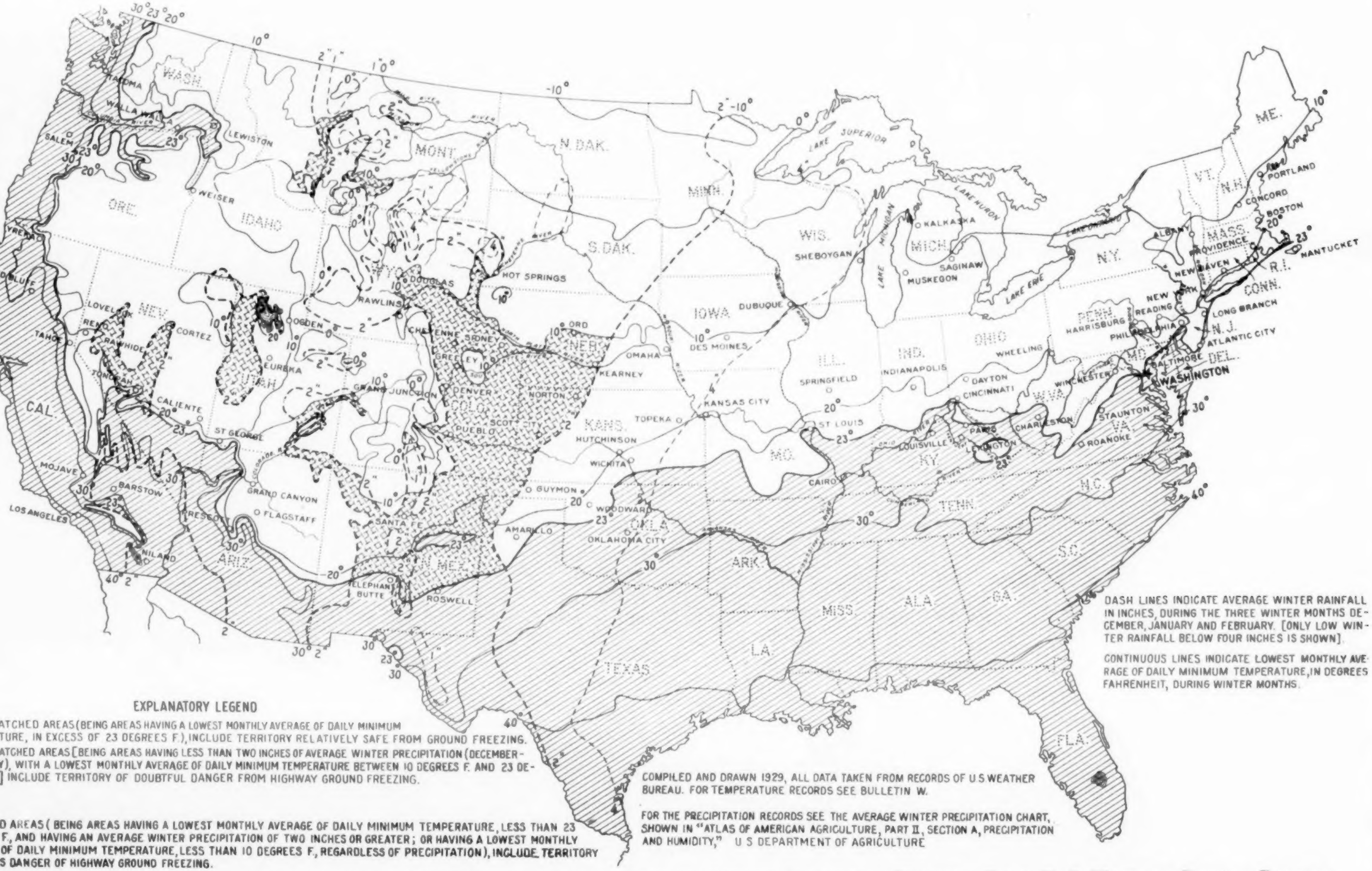

FIGURE 6.—ISOTHERMAL GUIDE MAP FOR USE IN DETERMINING AREAS SUBJECT TO GROUND FREEZING. COMPILED FROM U. S. WEATHER BUREAU RECORDS

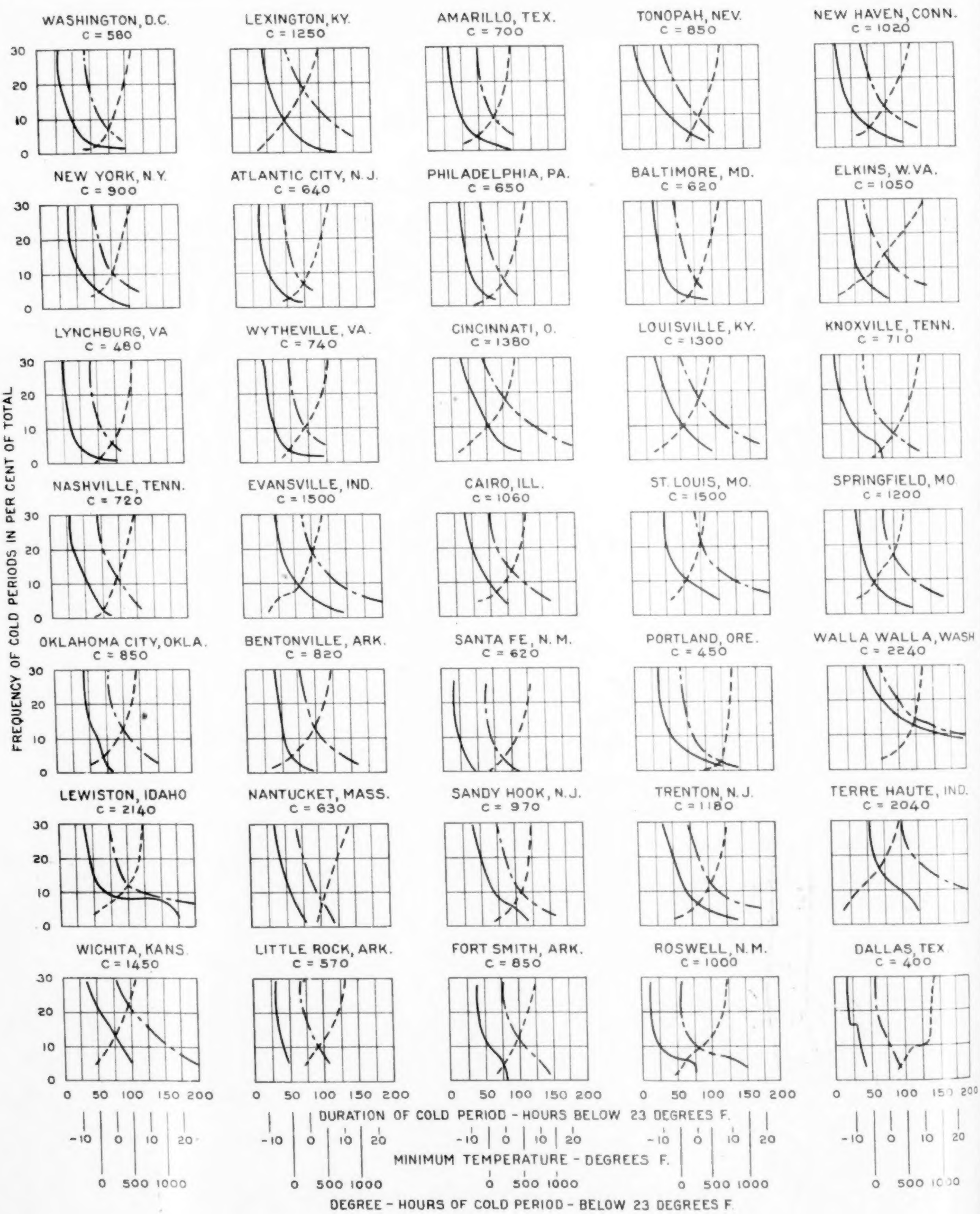

FIGURE 7.—DURATION-FREQUENCY CURVES, MINIMUM TEMPERATURE-FREQUENCY CURVES, AND DEGREE-HOUR-FREQUENCY CURVES FOR 35 SELECTED WEATHER BUREAU STATIONS

The general problem of temperature study as affecting highway design has been, for convenience of consideration, divided into two subdivisions of study, the one completed study being shown in graphic presentation by the use of a series of isothermal lines and the other by a series of isothermo-chronal lines. From the facts developed in the course of the work on the two subdivisions of study it now seems advisable to take up a comparative study of the two and consider the results as two parts of one general problem. As a means for so doing, it was found convenient to prepare a third map (fig. 9) showing an index line marking probable objectionable frost occurrence across the United States based on the most adverse conditions of occurrence as indicated by a combined study of the isothermals (shown in fig. 6) and of the isothermo-chronals (shown in fig. 8). For convenience of reference Figure 9 has been designated as a "highway ground-freezing index map" of the United States. It will be noted that no isohyetals are shown in Figure 9, as these data have already been presented in Figure 6.

PROPOSED EXTENSION OF METHOD USED IN THIS PAPER

The question has arisen as to whether a similar method of analysis and digest may not be used to show the relative depth of ground-freezing occurrence for various localities throughout the United States. A research of this sort, following the method used in this paper and accompanied by tabular presentations and charts, might serve as a basis for the study of subgrade soils from the viewpoint of frost occurrence. As in the present case, such a study would be based on an assumed standard average condition of soil type, soil moisture content, degree of compactness of soil, conditions of cover and shade, degree of exposure to sun and to wind, topographic placement as to altitude and slope, and other modifying conditions. This proposition is not treated in the present paper but has arisen from a discussion thereof, and it is suggested as a matter which might well be given study in the future.

CONCLUSIONS SUMMARIZED AND APPLICATIONS DISCUSSED

A brief summarized discussion of the above presented matter and of another related study may be pertinent. In the development of this study for presentation as a method available for practical use by the highway engineer dealing with the frost-occurrence phase of the ground freezing problem, the endeavor has been throughout to present a digest of frost-occurrence facts. The primary objective has been to develop a method by which the records of cold period occurrence in the United States may be presented in simple and readily usable graphic form. The few simple charts developed are intended for use as a reference guide through the use of which the frost-occurrence phase of the highway ground-freezing problem may be readily related to, and for any given location of local area studied jointly with, the other modifying phases of the entire general problem of highway ground-freezing occurrence. A study of other modifying influences which affect ground freezing, including variation in soil types, soil moisture content, conditions of cover or exposure, conditions of geographic or topographic placement, is not included as part of the objective of the present paper. It has been sought merely to present the facts of cold-period occurrence as obtained from a digest of existing weather records, and to work out a method of presentation of the relation of cold period occurrence to highway ground freezing occurrence by which the existing records of climatological data may be rendered conveniently applicable for study of the ground-freezing problem as affecting highway design. The three phases of presentation herein made, comprising as a whole a method for applying records of temperature occurrence to the ground freezing problem of highway design, are as follows:

(1) An isothermal study, considering the problem from the standpoint of the intensity and frequency of low temperature occurrence.

(2) An isothermo-chronal study, considering the problem from the combined standpoint of low temperature intensity, cold-period duration, and frequency of occurrence

(3) A highway ground-freezing index study, combining the most adverse conditions affecting highway ground freezing as developed by studies (1) and (2) and presenting the result graphically in the form of a highway-ground-freezing index line for the United States, based on the existing records of past weather occurrence.

It should be noted that the general analysis of this problem and the method above outlined are not dependent upon any values assumed or computed. For the few values assumed as part of the development of the study the actual range of possible variation is relatively small. Minor modification of one value or another would not alter largely the final position of the tentative highway ground-freezing index line. The selection of a critical depth of 4 inches instead of 3 inches, below the surface, if other assumed values were unchanged, would produce an index line for objectionable highway ground freezing approximately parallel to and located a few miles north of the index line as developed in the present study. The selection of a different critical depth, however, would bring up at once the question whether the allowable frequency ought not also to be modified, a less value of allowable frequency being assumed for frost occurrence passing the 4-inch depth than has been allowed for frost occurrence passing the 3-inch depth. If it were decided that such a modification should be made, a compensating factor for the change in critical depth would be thus introduced and the resulting highway ground-freezing index line would remain relatively unchanged from the position of highway ground-freezing index line, as developed in the present study.

It will be noted that the method as outlined is equally adaptable to the values assumed and computed or to such modified values as may be assumed or computed. It will be noted also that the presentation of the facts of cold occurrence is in such form as to be available for use in any given locality with such minor modification of critical values as will fit local conditions, according to the experience and judgment of the local highway authorities. The establishment of a more or less severe standard of allowable frequency of frost occurrence beyond a given depth based on an economic study, comparing probable highway ground-freezing damage as against estimated additional construction cost required to prevent the occurrence of that damage, becomes possible by variation of the critical value of isothermal or isothermo-chronal for any given locality. With the critical value altered the study may proceed, using for the frost-occurrence phase of the study the same charts and maps which would have been used had the tentative critical values of isothermal and isothermo-chronal developed in the course of the present study been found suitable. The end desired in the present study is that the records of cold-period occurrence as to intensity, duration, and frequency shall be made available in simple and nonconfusing form for use in the study of ground freezing as affecting highway design. The method here outlined is offered for use as a practical means of accomplishing this end.

Figure 8.—Isothermo-Chronal Map of the United States Showing Lines of Equal Degree-Hours of Cold Period Occurrence (Below 23° F.)

Figure 9.—Map Showing Critical Index Line for Highway Ground Freezing, Based on Most Adverse Existing Conditions, as Shown by Combined Study of Figures 7 and 9

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UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL AID ROAD CONSTRUCTION

AS OF

APRIL 30,1930

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal aid allotted	MILEAGE			Estimated total cost	Federal aid allotted	MILEAGE				
				Initial	Stage[1]	Total			Initial	Stage[1]	Total		
Alabama	2,120.6	$ 2,004,449.68	$ 985,810.90	69.8	21.0	90.8	$ 824,724.69	$ 410,570.93	47.6	1.1	48.7	$ 4,056,796.43	Alabama
Arizona	767.9	4,159,473.73	3,135,588.24	137.5	175.6	313.1	130,751.34	98,442.65	.6	19.2	19.8	2,164,545.60	Arizona
Arkansas	1,726.0	5,530,742.55	2,622,939.34	143.9	33.5	177.4	1,375,360.76	589,581.83	60.7	18.9	79.6	2,173,046.38	Arkansas
California	1,865.4	7,283,127.24	2,929,074.69	157.5	24.9	182.4	639,997.57	354,314.86	9.8	16.2	26.0	2,782,525.77	California
Colorado	1,179.6	4,802,813.72	2,528,065.02	191.1	38.7	229.8	493,408.81	273,189.10	23.1	9.3	32.4	2,945,561.18	Colorado
Connecticut	240.3	2,090,867.97	940,716.39	7.9		7.9	865,678.07	241,903.04	13.8		13.8	778,000.92	Connecticut
Delaware	258.2	458,267.70	151,293.87	7.7		7.7	778,018.40	371,119.96	40.9		40.9	287,346.06	Delaware
Florida	474.3	5,567,349.78	2,578,887.73	126.3	5.5	131.8						1,782,889.95	Florida
Georgia	2,729.0	1,322,274.01	632,039.51	49.6	.8	50.4	816,165.49	401,875.29	42.4	5.0	47.4	4,810,959.46	Georgia
Idaho	1,193.9	854,241.38	515,387.33	64.3	27.8	92.1	437,011.84	264,237.30	24.5		24.5	1,729,938.70	Idaho
Illinois	2,034.6	15,384,518.19	6,781,398.40	433.3		433.3	3,115,516.07	1,247,835.84	62.2	38.0	100.2	6,765,639.24	Illinois
Indiana	1,344.0	7,884,191.46	3,703,856.95	245.0		245.0	1,795,791.91	830,079.97	55.6		55.6	2,387,368.46	Indiana
Iowa	3,158.7	616,681.32	258,995.00	19.1		19.1	7,653,136.07	3,252,334.85	58.7	204.7	263.4	1,892.77	Iowa
Kansas	2,787.2	4,645,497.37	2,160,681.89	260.5	10.3	270.8	1,025,380.95	510,678.44	55.2	10.7	65.9	2,848,480.89	Kansas
Kentucky	1,405.2	4,210,233.39	1,998,677.24	230.2	18.1	248.3						2,805,862.50	Kentucky
Louisiana	1,355.7	4,168,691.97	2,037,693.63	126.7	12.5	139.2	1,100,679.14	532,966.32	37.0	4.9	41.9	1,892,079.58	Louisiana
Maine	520.0	1,906,021.13	736,937.56	47.5		47.5	228,130.16	108,074.89	10.1		10.1	1,916,752.53	Maine
Maryland	630.7	1,403,037.45	674,833.10	58.3		58.3	1,070,109.23	430,439.09	22.2	12.6	34.8	480,939.45	Maryland
Mass. .husetts	657.6	3,194,615.51	979,971.48	43.8	2.6	46.4	479,176.44	205,634.08	11.7		11.7	2,561,268.16	Massachusetts
Michigan	1,612.8	9,840,644.44	4,191,186.45	222.2	30.5	252.7	200,000.00	100,000.00	11.1		11.1	3,359,523.89	Michigan
Minnesota	4,010.0	8,660,604.64	2,967,010.00	197.7	182.8	380.5	2,976,084.72	1,222,337.21	32.7	95.3	128.0	105,122.79	Minnesota
Mississippi	1,810.5	1,846,209.28	716,929.45	65.6	7.7	73.3	48,835.05	24,417.52	.1		.1	3,521,493.59	Mississippi
Missouri	2,445.8	6,989,724.78	2,522,488.79	98.2	68.9	167.1	6,265,936.81	2,105,808.89	94.8	61.2	156.0	1,138,426.58	Missouri
Montana	1,722.3	7,605,580.72	4,445,126.75	528.1	12.9	541.0	999,393.08	548,580.63	70.7	47.0	117.7	3,910,324.96	Montana
Nebraska	3,557.0	6,598,571.96	3,196,617.76	320.2	109.5	429.7	1,995,777.22	744,065.25	31.8	67.8	99.6	2,622,644.02	Nebraska
Nevada	1,160.0	1,139,782.79	1,012,696.90	72.0	109.3	181.3	320,691.26	284,934.17		32.9	32.9	1,076,347.59	Nevada
New Hampshire	350.6	496,706.30	152,386.14	5.5	2.1	7.6	130,463.20	44,724.92	3.5		3.5	607,316.42	New Hampshire
New Jersey	500.2	4,136,550.77	852,015.00	56.8		56.8	1,495,836.71	259,335.00	17.3		17.3	1,456,305.08	New Jersey
New Mexico	1,916.1	3,958,028.87	2,573,501.57	203.7	20.9	224.6	36,820.67	15,376.50	.8		.8	1,533,604.66	New Mexico
New York	2,458.2	18,480,217.76	3,787,505.00	253.2		253.2	8,055,650.00	1,519,660.00	101.5		101.5	8,217,060.99	New York
North Carolina	1,764.9	2,449,397.48	1,211,346.68	147.7	22.5	170.2	555,930.70	273,540.69	20.4		20.4	3,274,270.55	North Carolina
North Dakota	4,159.7	1,681,575.50	758,114.10	304.3	120.7	425.0	1,437,613.87	710,224.60	211.2	201.1	412.3	1,862,745.49	North Dakota
Ohio	2,178.5	14,739,815.88	4,495,146.34	255.0	18.8	273.8	7,696,613.53	2,484,111.08	133.4	21.4	154.8	2,683,163.25	Ohio
Oklahoma	1,904.3	2,525,942.07	1,086,589.78	68.6	29.8	98.4	2,064,986.06	900,879.15	56.9	32.2	89.1	1,677,751.44	Oklahoma
Oregon	1,147.7	3,099,574.37	1,867,346.97	187.8	56.2	244.0	2,541,838.63	1,430,849.49	66.3	29.2	95.5	708,673.78	Oregon
Pennsylvania	2,268.1	16,293,282.65	3,982,904.02	233.7	14.1	247.8	3,378,800.30	982,882.94	56.5		56.5	3,880,004.46	Pennsylvania
Rhode Island	184.8	1,884,585.72	534,553.58	27.8		27.8	129,559.02	64,779.50	.4		.4	657,690.02	Rhode Island
South Carolina	1,896.7	3,313,377.98	1,188,925.77	110.3	22.3	132.6	1,703,630.88	606,031.44	36.9	33.0	69.9	1,363,608.88	South Carolina
South Dakota	3,463.6	3,983,700.85	2,129,358.04	424.8	97.4	522.2	1,035,998.25	559,011.83	98.1	79.7	177.8	1,258,005.23	South Dakota
Tennessee	1,243.3	1,871,857.29	817,145.16	74.8		74.8	863,957.19	431,978.59	26.7	12.5	39.2	3,143,092.20	Tennessee
Texas	6,786.6	11,042,254.40	4,467,528.41	330.5	84.8	415.3	4,239,420.02	1,629,901.44	143.1	79.5	222.6	5,736,367.72	Texas
Utah	988.9	752,789.23	502,869.44	31.6		31.6	670,819.20	490,941.75	28.4	89.6	118.0	1,010,284.26	Utah
Vermont	255.2	1,909,459.07	526,508.11	34.5	2.6	37.1	575,492.53	170,919.86	10.2		10.2	186,919.47	Vermont
Virginia	1,417.6	4,234,953.10	1,982,279.12	174.3	23.3	197.6	1,138,954.99	551,746.88	39.0	2.2	41.2	906,962.51	Virginia
Washington	925.8	2,911,647.90	1,132,300.00	55.6	40.2	95.8	1,302,420.65	507,000.00	45.0		45.0	1,538,673.29	Washington
West Virginia	717.1	2,842,201.32	1,136,062.75	69.1	12.4	81.5	1,054,295.45	468,023.81	15.3	21.5	36.8	885,321.29	West Virginia
Wisconsin	2,265.5	2,986,320.49	1,303,185.13	114.5	1.7	116.2	3,144,764.00	1,256,500.00	58.0	44.6	102.6	1,893,186.87	Wisconsin
Wyoming	1,757.1	1,333,730.81	862,873.64	118.6	24.3	142.9	266,012.65	174,637.77	20.1	43.9	64.0	1,405,545.48	Wyoming
Hawaii	39.5	964,949.48	384,686.43	23.2		23.2						1,682,039.16	Hawaii
TOTALS	83,475.3	228,058,133.46	93,139,625.55	7,229.9	1,487.0	8,716.9	79,155,631.58	30,686,469.33	2,006.3	1,335.2	3,341.5	108,464,160.05	TOTALS

[1] The term stage construction refers to additional work done on projects previously improved with Federal aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

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